AD/A-004 008

ARTIFICIAL ICING TESTS CH-47C HELICOPTER

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Edwards Air Force Base, California

August 1974

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER USAAEFA PROJECT NO. 73-04-1	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ARTIFICIAL ICING TESTS CH-47C HELICOPTER		5. TYPE OF REPORT & PERIOD COVERED FINAL REPORT 8 April – 2 May 1974
		6. PERFORMING ORG. REPORT NUMBER USAAEFA PROJECT NO. 73-04-1
7. AUTHOR(s) MAJ CARL F. MITTAG, CPT MARVIN L. HANKS, CPT JAMES C. O'CONNOR, CPT LOUIS KRONENBERGER JR		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US ARMY AVIATION ENGINEERING FLIGHT ACTIVITY EDWARDS AIR FORCE BASE, CALIFORNIA 93523		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS A1-4-R0075-00A1-EJ
11. CONTROLLING OFFICE NAME AND ADDRESS US ARMY AVIATION ENGINEERING FLIGHT ACTIVITY EDWARDS AIR FORCE BASE, CALIFORNIA 93523		12. REPORT DATE AUGUST 1974
		13. NUMBER OF PAGES 71
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE NA

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Artificial icing tests	Rotor blades
CH-47C helicopter	Ice particle impact
Icing environment operational safety	Shed ice particle ingestion
Icing limitations verification	Lateral vibrations
Ice shedding	Ice detection and accretion rate system

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The United States Army Aviation Engineering Flight Activity conducted a limited evaluation of the CH-47C helicopter in artificial icing conditions from 8 April 1974 through 2 May 1974. These tests were conducted at Moses Lake, Washington, and consisted of 2.9 hours in an artificial icing environment. Artificial icing tests were conducted to evaluate the capability of the CH-47C helicopter to safely operate in an icing environment and to verify the icing limitations presented in the

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20. Abstract

operator's manual. Additionally, the capabilities of the standard anti-ice systems and installed special equipment were evaluated. Ice shedding from the rotor system, resulting in rotor blade damage caused by rotor blade and ice particle impact, was identified as a deficiency. Also noted as a deficiency was the ingestion of shed ice particles which resulted in engine foreign object damage. Ice shedding from the rotor system, resulting in damage to the aft rotor head rain cover and the upper left engine oil cooler vent, and the asymmetrical shedding of ice from the CH-47C rotor system, which resulted in moderate one-per-rotor-revolution lateral vibrations, were noted as shortcomings. An ice detection and accretion rate system is an enhancing feature for helicopters required to operate in icing conditions. The artificial ice cloud depth precluded simultaneous icing of the entire test helicopter. Within the scope of this test, the CH-47C helicopter equipped with unprotected T55-L-11A engines does not possess the capability to safely operate in an icing environment.

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PREFACE

The United States Army Aviation Engineering Flight Activity wishes to acknowledge the cooperation and support provided during the CH-47C helicopter artificial icing tests by the personnel of the Port of Moses Lake, Moses Lake, Washington; 116th Assault Helicopter Company, 10th Aviation Battalion; and B Company, 9th Aviation Battalion, 9th Infantry Division, Fort Lewis, Washington; Seattle Air Route Traffic Control Center; and the Grant County Federal Aviation Administration personnel.

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INTRODUCTION

BACKGROUND

1. The Department of the Army requested that first-line Army helicopters be tested for flight in artificial icing conditions generated by a helicopter icing spray system (HISS). The United States Army Aviation Engineering Flight Activity (USAAEFA) was directed by the United States Army Aviation Systems Command (AVSCOM) to conduct the icing tests (ref 1, app A). A test plan (ref 2) was prepared in response to the AVSCOM test directive. Coordination was initiated between USAAEFA and the Port of Moses Lake, Washington, to arrange for the conduct of the CH-47C test program at Moses Lake, beginning in March 1974.

TEST OBJECTIVES

2. The objectives of this evaluation were as follows:

a. To determine the capability of the CH-47C helicopter to safely operate in an icing environment.

b. To verify the icing limitations presented in the CH-47C operator's manual (ref 3, app A).

c. To evaluate the capabilities of the standard CH-47C anti-ice systems and installed special equipment.

DESCRIPTION

3. The test helicopter was a production CH-47C, serial number (SN) 69-17126, manufactured by the Boeing Vertol Company. The helicopter was powered by two Lycoming T55-L-11A turboshaft engines. A detailed description of the standard CH-47C helicopter is contained in the operator's manual. All tests were conducted with the cargo mirror removed, engine inlet screens removed, cargo hook stowed, and cabin heat and anti-ice systems ON. Nonstandard equipment installed on the airframe exterior to assist in the conduct of this evaluation included an ice accretion indicator probe (visual probe) located on the forward pylon above the copilot's overhead plexiglas panel, a Rosemount ice detection and accretion rate system mounted on the forward pylon over the pilot's overhead plexiglas panel, and a heated total temperature probe located between the pilot and copilot chin bubbles (photos 6, 10, and 11, app C). A description of the icing spray system installed on a CH-47C helicopter (SN 68-15814) .is presented in references 4 and 5, appendix A, and in appendix B.

TEST SCOPE

4. The CH-47C artificial icing tests were conducted in the vicinity of Moses Lake, Washington, from 8 April through 2 May 1974 by USAAEFA personnel. Five test flights for a total of 10.9 productive hours were flown, of which 2.9 hours were in the artificial icing environment. Flight limitations contained in the operator's manual and the safety-of-flight release (ref 6, app A) were observed during the testing. The tests were accomplished at an average gross weight of 28,200 pounds, a mid center-of-gravity (cg) location of 333.2 inches, density altitudes from 4960 to 10,840 feet, airspeeds of 70 to 90 knots indicated airspeed (KIAS), and a rotor speed of 235 rpm. Icing was accomplished at static temperatures of -6.0°C to -8.5°C and liquid water content (LWC) from 0.25 to 1.05 gram/meter^3. Tests at lower ambient temperatures were not conducted due to climatic conditions at the test site.

TEST METHODOLOGY

5. The following procedure was used to accumulate ice on the airframe and rotor systems of the test aircraft. The standard windscreen, engine, pitot tube, and stability augmentation system (SAS) port anti-ice systems were activated prior to entering the spray cloud. The test aircraft was then positioned in the spray cloud to accumulate a predetermined amount of ice. Qualitative and quantitative tests were conducted at a position clear of the spray cloud after accumulation of a desired amount of ice. Results of these tests were compared to base-line tests conducted prior to icing the test helicopter. Because of the limited spray cloud dimensions, the test aircraft could not be totally immersed in icing conditions. The test procedure was to separately ice either the forward rotor system, the aft rotor system, or the windshield/lower fuselage.

6. A Rosemount ice detection and accretion rate system and a USAAEFA-fabricated ice accretion measuring device were used to measure rate of accretion and the incremental accumulation of ice. In-flight photography was used to document these icing levels. Above-freezing temperatures on the surface prevented postflight measurement of the accumulated ice. Data were recorded during these tests on magnetic tape, photopanel, and voice recorder. A detailed description of the instrumentation is provided in appendix C.

7. Test techniques and data analysis methods, as well as the Handling Qualities Rating Scale (HQRS) used to augment pilot comments relative to handling qualities (fig. 4), are presented in appendix D. The methods used to determine cloud parameters and definitions of icing types and severities are also presented in appendix D.

RESULTS AND DISCUSSION

GENERAL

8. A limited artificial icing evaluation was conducted to determine the capability of the CH-47C helicopter to safely operate in an icing environment. Tests were conducted to verify the icing limitations stated in the operator's manual. Additionally, the capabilities of the standard anti-ice systems and installed special equipment were evaluated. Ice shedding from the rotor system, resulting in rotor blade damage caused by rotor blade and ice particle impact, was identified as a deficiency. Also noted as a deficiency was the ingestion of shed ice particles which resulted in engine foreign object damage (FOD). Ice shedding from the rotor system, resulting in damage to the aft rotor head rain cover and the upper left engine oil cooler vent, and the asymmetrical shedding of ice from the CH-47C rotor system, which resulted in moderate one-per-rotor-revolution (1/rev) lateral vibrations, were noted as shortcomings. An ice detection and accretion rate system is an enhancing feature for helicopters required to operate in icing conditions. The artificial ice cloud depth precluded simultaneous icing of the entire test helicopter. Within the scope of this test, the CH-47C helicopter equipped with unprotected T55-L-11A engines does not possess the capability to safely operate in an icing environment.

SPRAY SYSTEM CHARACTERISTICS

9. Prior to commencing the icing tests, a wake turbulence and helicopter immersion evaluation was conducted with the CH-47C test helicopter behind the CH-47C HISS. Accurate aircraft positioning and stabilized flight conditions could be maintained in the HISS downwash at standoff distances less than 300 feet. At distances greater than approximately 300 feet behind the HISS, the downwash effects of the rotor systems dissipated and disrupted the spray cloud, rendering it unusable for quantitative test purposes. Additionally, stabilized flight conditions could not be maintained in the test vehicle for standoff distances in excess of 300 feet. The most stable flight conditions for the test helicopter in the spray cloud were at a standoff distance of approximately 110 feet. Stabilized flight at this distance could be achieved with minimal cyclic inputs and torque changes of ±2 percent. The CH-47C helicopter is shown in the spray cloud in photo A.

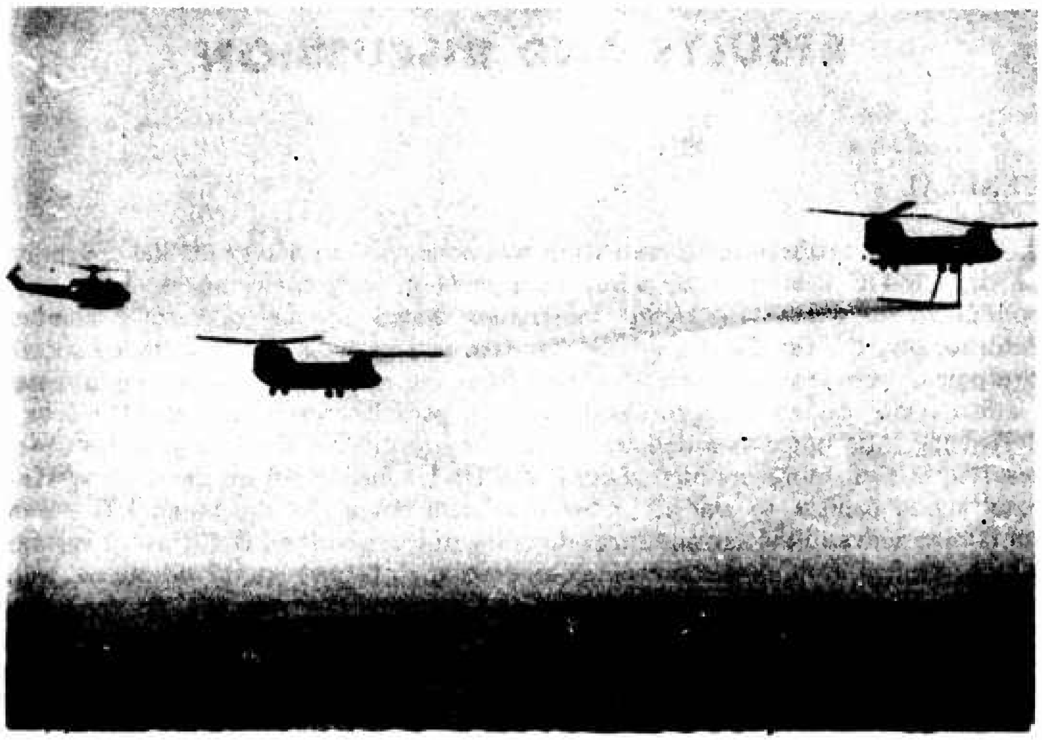


Photo A. Typical Icing Flight Formation.

10. The usable artificial icing cloud produced by the HISS was approximately 5 feet thick by 75 feet wide by 200 feet long. The cloud width and length permitted positioning of the test helicopter in the cloud to simultaneously ice both the advancing and retreating blades of one rotor system. The HISS spray cloud vertical thickness (5 feet) required separate and individual icing of the forward rotor, the aft rotor, the windshield/chin bubble area, and the lower fuselage area. Fragmented icing of the helicopter does not duplicate a natural icing environment. The level flight, autorotational descent, and vibration data obtained from these artificial icing tests do not accurately quantify the effects of an icing environment affecting the total helicopter. Further tests, utilizing a modified HISS or other device which creates a spray cloud of sufficient size to totally immerse the test helicopter, are recommended to completely evaluate operation of the CH-47C helicopter in an artificial icing environment.

ICING SEVERITY

11. Icing severity tests were conducted to quantify the accretion and rate of ice accumulation on the CH-47C helicopter. These tests were flown in various combinations of temperature and LWC. The test conditions and significant test results are presented in table 1. Each temperature and LWC combination was investigated, utilizing a build-up program of time in the icing cloud prior to continuing with the next more severe combination (colder temperature and/or higher LWC). Appendix D describes the methods for determining the desired icing conditions and the method of exposing the test helicopter to the icing environment.

12. Ice thickness observed on the visual ice accretion probe during this evaluation varied from 1/16 inch to 1 inch of glime ice (mixture of clear and rime). Typical ice formations on the forward and aft pylon areas are shown in photos B and C, respectively. The amount and type of rotor blade ice accumulation could not be postflight-documented due to the above-freezing ambient temperatures on the ground. If a quantitative measurement of rotor blade ice accretion is desired in future tests, a method of in-flight measurement must be devised or the ambient temperature must be low enough to permit ground measurement of the ice accumulation. The amount of ice accumulated during each flight was limited by the quantity of water contained in the spray helicopter and the test techniques dictated by the limited spray cloud vertical thickness.

Photo B. Ice Accumulation on the Forward Rotor System and Pylon Area.

Table 1. Icing Test Conditions and Results.[1]

Flight Number	Programmed Icing Severity	Average Static Temperature (°C)	Programmed Liquid Water Content (gram/meter^3)	Time in Icing Condition (min)	Component Iced	Average Density Altitude (ft)	Average True Airspeed (kt)
1	Light	-6.0	0.25	5 10 15	Fwd rotor Fwd rotor Aft rotor	4960	95
2	Heavy	-6.5	[2]1.05	10 [3]4.5	Fwd rotor Aft rotor	5480	93
3	Light	-6.5	0.25	30 21	Fwd rotor Aft rotor	7380	102
4	Light	-8.5	0.25	10 5 26 9	Fwd rotor Aft rotor Fwd rotor Fwd rotor	10,380	96
5	Moderate	-8.5	0.50	11 15	Fwd rotor Fwd rotor	10,840	98

[1]Average cg location: 333.2 inches.
Rotor speed: 235 rpm.
Average gross weight: 28,200 pounds.
[2]Estimated value. Flowmeter on spray system malfunctioned.
[3]Icing terminated. Spray system water depleted.

Photo C. Ice Accumulation on the Aft Rotor System and Pylon Area.

13. The icing severity indicated by the Rosemount ice detection and accretion rate system agreed with the HISS severity predicted from previously conducted calibrations (app D). The intermittent immersion of the visual probe in the spray cloud precluded correlating ice accretion on the visual probe with the Rosemount indication. Rosemount indications were obtained by positioning the sensor in the spray cloud at the start and end of each icing segment. Immediate and accurate fuselage icing rate information was available to the pilot. The Rosemount ice detection and accretion rate system provides the pilot with the necessary information needed to identify fuselage icing conditions. An ice detection and accretion rate system is an enhancing feature for helicopters required to operate in icing conditions.

14. No aircraft safety-of-flight limitations were encountered while operating the CH-47C helicopter in light-to-heavy icing conditions at static temperatures higher than -6.5°C and in light icing conditions at -8.5°C. Suspension of the tests, due to engine damage incurred on flight 5 (para 22), precluded completion of the planned tests at lower temperatures. Icing severity tests should be conducted at lower temperatures (less than -8.5°C) to fully evaluate the flight characteristics of the CH-47C helicopter in artificial icing conditions.

ICE SHEDDING CHARACTERISTICS

15. Ice shedding characteristics and the subsequent effects on the test aircraft were determined at the test conditions shown in table 1. Pilot observations and high-speed motion picture photography were used to document ice shedding. Ice shedding characteristics were influenced by both temperature and the level of accretion. Symmetrical ice shedding from the rotor systems was observed on flights 1 through 3 in light-to-heavy icing conditions at or above a static temperature of -6.5°C and on flight 4 in light icing conditions at -8.5°C. Previously tested aircraft rotor systems (UH-1H and AH-1G, refs 7 and 8, app A) exhibited a symmetrical shed pattern where ice was shed completely outboard of a specific spanwise blade station. The shed point moved further outboard on the blade as static temperature decreased. Symmetrical shedding did not occur inboard of this blade station. The CH-47C rotor system exhibited similar shed characteristics outboard of the temperature-controlled shed point, *ie*, ice was consistently shed symmetrically from the rotor blades. Inboard from the shed point, a distinct difference in shed characteristics was noted. Sections of ice were intermittently shed from random spanwise blade stations inboard of the temperature-controlled shed point, probably as a result of normal blade bending. On all flights the symmetrical shedding of ice outboard of the temperature-controlled shed point was observed at 4 to 6-minute intervals. These periodic symmetrical shedding characteristics were consistent and predictable until icing conditions were encountered which resulted in an asymmetrical ice shed (paras 18 and 23).

16. The ice shed from the CH-47C rotor systems generally remained in the tip path plane, striking succeeding blades of the same rotor and/or blades of the other rotor system. Postflight inspection, after flight 5, revealed rotor blade skin damage to the lower surface of five rotor blades. The surface deformations ranged in size from 1/4 to 1-1/2 inches spanwise, 3/4 to 6 inches chordwise, and 3/100 to 1/10 inch deep. The aft rotor blades received 80 percent more dents than the forward blades, with a single aft blade receiving the most damage (18 dents), as shown in photo D. In accordance with the dent criteria of reference 9, appendix A, four rotor blades required replacement and an Equipment Performance Report (EPR) (ref 10) was submitted. Ice shedding from the rotor system, resulting in rotor blade damage caused by rotor blade and ice particle impact, is a deficiency. Careful postflight inspection of the rotor blades is recommended following flight in icing conditions. The following CAUTION should be placed in chapter 10 of the operator's manual:

CAUTION

> Ice accumulated on rotor blades during flight in icing conditions may shed and impact blades of both rotor systems. This rotor blade impact with shed ice may cause sufficient damage to necessitate blade change. Following flight in icing conditions, all rotor blades should be carefully inspected, with particular attention directed to the lower skin surfaces of the blades.

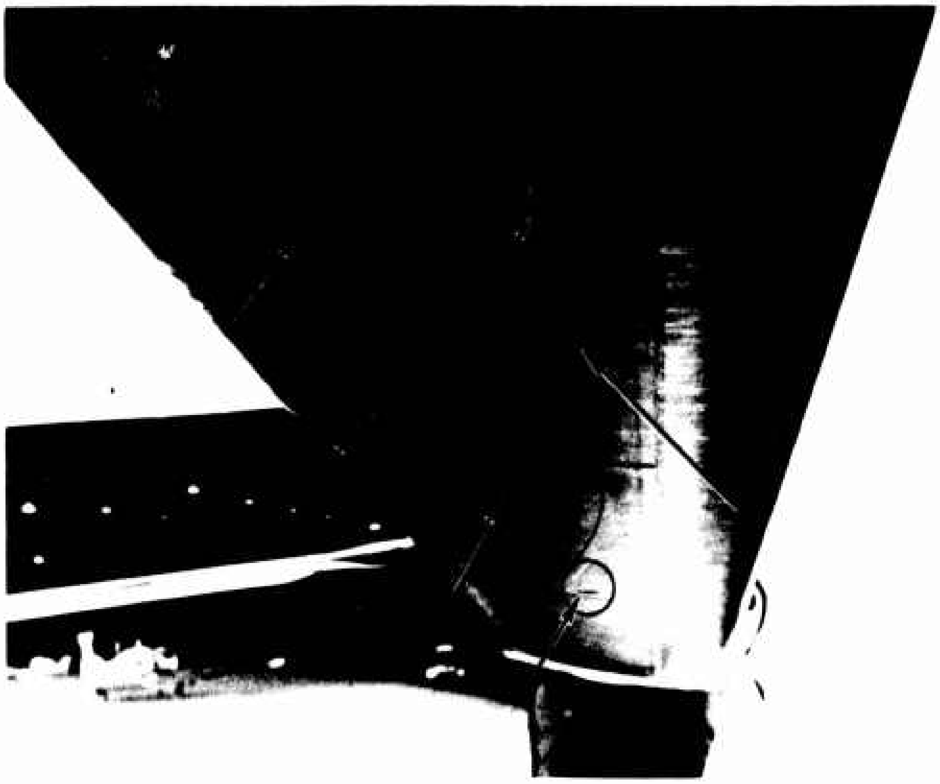


Photo D. Blade Damage Caused by Impact With Shed Ice Particles.

17. Ice shed from the rotor systems also impacted with portions of the fuselage. Postflight examination of the fuselage revealed numerous dents along the left side of the fuselage. The most extensive fuselage damage was observed following flight 5 and was confined to the upper left engine oil cooler inlet and the aft rotor head rain cover (photos E and F). Ice shedding from the rotor system, resulting in damage to the aft rotor head rain cover and the upper left engine oil cooler inlet, is a shortcoming. If icing conditions are encountered, a careful postflight examination of the fuselage should be accomplished, with particular attention directed to the upper left side of the aft pylon. The following NOTE should be placed in chapter 10 of the operator's manual:

NOTE

> If icing conditions are encountered, ice shed from the rotor system may cause damage to the helicopter fuselage. A careful postflight examination of the fuselage, with particular attention directed to the upper left side of the aft pylon, should be accomplished.

Photo E. Aft Rotor Head Rain Cover Damage Caused by Impact With Shed Ice Particles.

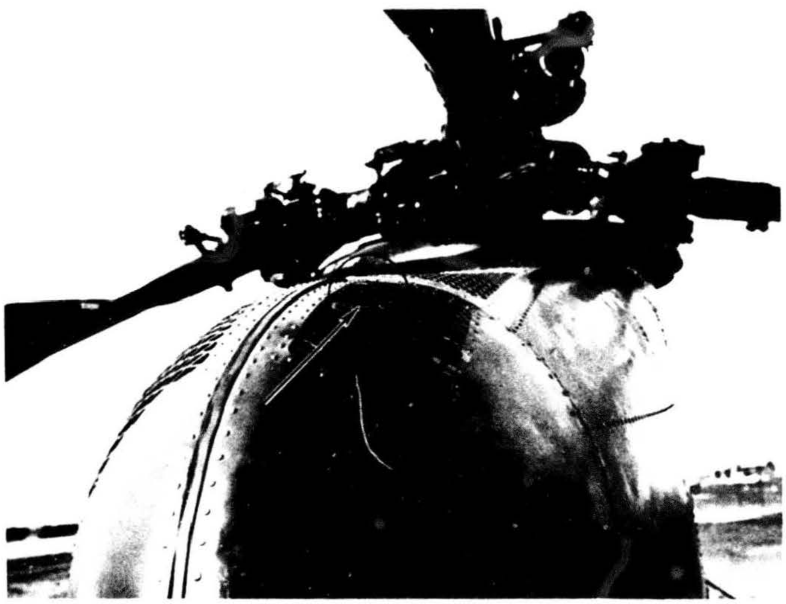


Photo F. Oil Cooler Vent Damage Caused by Impact With Shed Ice Particles.

18. Two asymmetric ice sheds from the forward rotor system were observed on flight 5. The first asymmetrical shed occurred after 10 minutes of forward rotor immersion in programmed moderate artificial icing conditions at -8.5°C static temperature. The asymmetrical ice loading condition returned to a symmetrical ice loading by natural shedding after approximately 2 minutes. A second asymmetrical ice shed occurred after 13 minutes of forward rotor system immersion in the same artificial icing environment. Natural shedding returned the rotor system to a symmetrical ice load condition after approximately 3 minutes. Both of the asymmetric ice shed conditions were characterized by moderate 1/rev lateral vibrations. These lateral vibrations adversely affected reading of flight and engine instruments and required extensive concentration by the pilot. In addition, the vibration tended to displace the pilot and induce large lateral control inputs. The difficulty in reading flight and engine instruments, and the large control inputs, required extensive pilot compensation to accomplish flight in simulated instrument meteorological conditions (IMC) (HQRS 6). The asymmetrical shedding of ice from the CH-47C rotor system, which results in moderate 1/rev lateral vibrations, is a shortcoming. A detailed discussion of the asymmetrical ice shed-induced vibration characteristics is presented in paragraph 23.

19. Three methods of inducing rotor system ice shedding were investigated. The methods used were thrust control rod (collective) oscillations of ±1 inch, rotor speed variations between 235 and 245 rpm (10-rpm increases and decreases), and circular cyclic control inputs of 3/4-inch radius. Although rotor system ice shedding was not observed every time these methods were used, they were each partially effective. Only small amounts of ice shedding could be induced utilizing all three methods. Rotor speed variation was found to be the most effective of the three techniques. On flight 5, following the asymmetrical ice shed, control activity (cyclic and collective pulses) was initiated to induce symmetrical ice loading on the forward rotor system. In this case, the control activity caused additional ice shedding from the rotor blades which aggravated, rather than improved, the unbalanced condition. The following WARNING should be placed in chapter 10 of the operator's manual:

WARNING

> During flight in icing conditions, asymmetrical ice shedding from the rotor system may result in moderate aircraft vibrations. Vigorous control activity may induce a more asymmetrical loading of ice on the rotor systems, further aggravating helicopter vibration levels. Large control movements should not be made in an attempt to reduce the low-frequency aircraft vibrations caused by rotor system asymmetrical ice loading.

20. An engine inlet FOD protection system, designed to operate in an icing environment, was not available for this test program. As recommended in the operator's manual, the engine inlet screens were removed prior to flight in the artificial icing environment. On flight 5, both engines received inlet guide vane and compressor blade damage (photo G) caused by shed ice entering the engine

inlet. The ingested particles lodged between the trailing edge of the inlet guide vanes and the leading edge of the first-stage compressor blades, causing deformation and twisting of the blades. Damage also occurred to the first-stage stator vanes in the right engine. Although both engines sustained FOD on the flight, there were no instrument fluctuations or other indications of the damage apparent to the aircraft crew. Engine temperature, pressures, and power indications remained normal. Postflight inspection of the engines revealed that the sustained damage was of sufficient magnitude to require replacement of both engines and an EPR was submitted (ref 11, app A). The test program was terminated at this point, since no method was available to preclude further engine FOD. The ingestion of shed ice particles which resulted in engine FOD is a deficiency. Further testing of the CH-47C helicopter should not be conducted until engine inlet protection is provided to preclude ice FOD to the engines. Additionally, CH-47C helicopters equipped with unprotected T55-L-11A engines should be restricted from flight into known or forecast icing conditions and the following WARNING placed in chapter 10 of the operator's manual.

WARNING

> Significant engine FOD can be sustained by unprotected T55-L-11A engines as a result of shed ice particle ingestion. The CH-47C helicopter equipped with unprotected T55-L-11A engines should not be flown into known or forecast icing conditions.

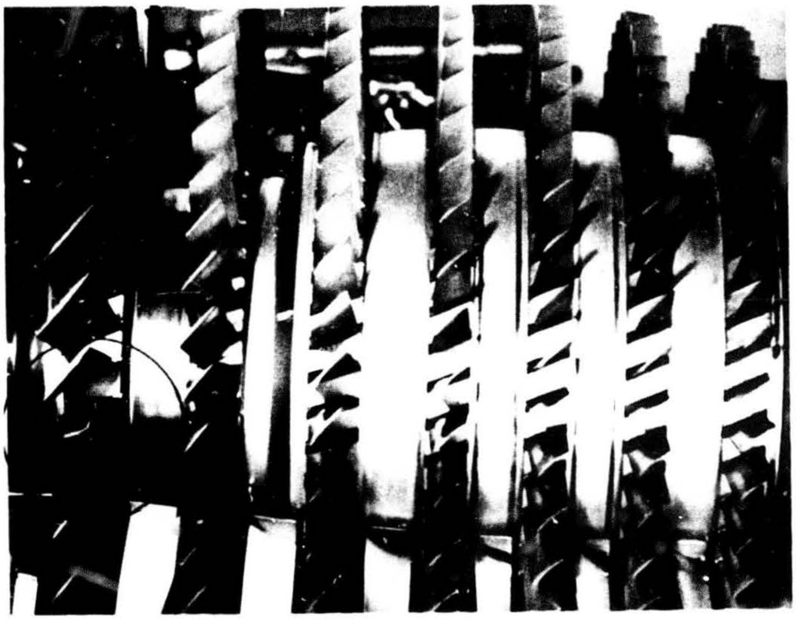


Photo G. Typical Turbine Blade Damage Caused by Ingestion of Shed Ice Particles.

21. The ice shedding characteristics of the CH-47C helicopter were observed during landing approach, hover, ground taxi, and shutdown. Following flight in artificial icing conditions, large particles of ice were thrown from the rotor system with sufficient force to cause personnel injury. The ice was shed in all directions and presented a potential hazard to ground personnel in the vicinity of the helicopter. The following WARNING should be placed in chapter 10 of the operator's manual:

WARNING

> Following flight into icing conditions, ice shed from the rotor blades and/or other rotating components presents a hazard to personnel during ground operation and shutdown of the helicopter. Ground personnel should remain well clear of the helicopter during landing, ground operation, and shutdown. Passengers/crewmembers should not exit the helicopter until the rotor rotation has stopped.

VIBRATION CHARACTERISTICS

22. Vibration characteristics were qualitatively and quantitatively evaluated during the test program. An accelerometer mounted to a plate installed in the pilot's seat pad was used to obtain vibration data at the pilot station. Figure 1, appendix E, depicts the pilot station vibration limits specified in paragraph 3.7.1(b) of military specification MIL-H-8501A (ref 12, app A). Representative vibration data (spectral plots) taken at the pilot's seat pad during specific events on flight 5 are presented in figures 2 through 22 of appendix E. These figures are arranged chronologically by event and grouped according to accelerometer axis.

23. Natural ice shedding, resulting in symmetrically balanced ice loading on both rotor systems, was observed on flights 1 through 4. Insignificant increases in aircraft vibration levels accompanied these sheddings. Asymmetrical ice shed-induced vibrations were recorded on flight 5 and the qualitative crew assessments were discussed in paragraph 18. Base-line vibration data, recorded prior to ice accumulation on the rotor systems, is presented in figures 2, 9, and 16 of appendix E. Comparing this condition with a condition of symmetrical forward rotor system ice accumulation (figs. 3, 10, and 17) confirms the qualitative assessment that symmetrical ice loading on the rotor systems insignificantly affected aircraft vibration levels at the pilot station. Asymmetrical ice loading of the forward rotor system resulted in the pilot station vibration levels shown in figures 4, 11, and 18. Comparison of these spectral plots with spectral plots of either the no-ice condition or the condition of symmetrical ice loading shows considerable increases in the vibration levels at the 1/rev and 6/rev frequencies in all axes. Although large increases in vibration levels are evident in all axes, the most pronounced increase is in the lateral direction. Vertical vibration levels at the 1/rev rotor frequency increased from the no-ice condition (0.06g) to the asymmetric condition (0.12g), as shown in figures 2 and 4. Vibration levels (1/rev) in the longitudinal direction increased from the no-ice condition (0.01g) to the asymmetric ice load

condition (0.04g), as shown in figures 16 and 18. Lateral axis vibrations at the 1/rev rotor frequency increased from the no-rotor-ice condition (0.02g) to the asymmetric ice load condition (0.14g), as shown in figures 9 and 11. Asymmetrical rotor system ice loading significantly increased aircraft vibration levels at the pilot station.

ICE PROTECTION SYSTEMS

24. The standard anti-ice systems of the CH-47C helicopter, consisting of engine anti-ice, heated pitot tube, SAS yaw port heating, and windshield anti-ice systems were evaluated throughout the test program. The standard anti-ice systems operated effectively and without failure. The engine air inlet fairings, engine transmission fairings, and the heated portion of the engine drive shaft fairings remained free of ice at all test conditions. The heated pitot tube remained clear of ice throughout the icing test program. When the windshield anti-ice system was activated 5 minutes prior to entering the artificial icing environment, as recommended by the operator's manual, satisfactory operation was observed and the windshield remained clear of ice. Prolonged icing of the lower fuselage, which would allow adequate evaluation of the heated SAS ports and chin bubbles, was not accomplished due to program suspension as a result of engine FOD (para 20). Further artificial icing tests of the CH-47C helicopter should be conducted to thoroughly investigate prolonged icing of the yaw SAS ports and chin bubbles. Within the scope of this test, the standard anti-ice systems functioned properly.

PERFORMANCE

Level Flight

25. A limited level flight performance evaluation of the CH-47C helicopter with T55-L-11A engines installed was conducted at the conditions shown in table 1. Level flight performance was degraded as ice was accumulated. Table 2 shows the degradation of level flight performance as an increase in engine power required to maintain a constant airspeed and altitude. The data in table 2 represent the largest power increases observed during these tests; the data were recorded after 14-1/2 minutes exposure to heavy artificial icing conditions at -6.5°C static temperature. The 11-percent increase in indicated engine torque (per engine) to maintain airspeed and altitude following ice accumulation shows that a degradation of endurance and range can be expected. This increase represents an additional 32 percent of power required to maintain these flight conditions. Because of the limited nature of this program and the spray system characteristics (inadequate vertical cloud thickness to totally immerse the test helicopter), a complete quantitative level flight performance assessment and its effects on the CH-47C mission profile could not be determined. Further icing tests should be conducted to completely evaluate ice accretion effects on the level flight performance of the CH-47C helicopter.

Table 2. Increases in Engine Power with Ice Accumulation.[1]

Icing Condition	Density Altitude (ft)	Static Outside Air Temperature (°C)	True Airspeed (kt)	Average Torque Each Engine (%)
No-ice	5400	-5.5	95	34
10 minutes forward rotor system	5560	-7.5	90	45
10 minutes forward rotor system plus 4.5 minutes aft rotor system	5680	-6.5	94	45

[1]Liquid water content: 1.05 gram/meter^3.
Average gross weight: 28,620 pounds.
Center-of-gravity location: 332.2 inches.
Ambient relative humidity: 46 percent.
Rotor speed: 235 rpm.

Autorotational Descent

26. Autorotational descent characteristics were evaluated under the conditions shown in table 1. Autorotational descents were conducted at 70 KIAS (the operator's manual recommended airspeed for minimum rate of descent) at the completion of each icing segment. Prior to entry into autorotation, the emergency engine trim switches were activated to simulate zero engine power delivered to the rotors. The thrust control rod was used to maintain rotor speed constant at 245 rpm. On all flights, a stabilized rotor speed of 245 rpm could be maintained following exposure to the artificial icing environment. As discussed in paragraph 10, both rotor systems could not be iced simultaneously. Simultaneous controlled icing of both ro. systems is required to properly evaluate the effects of ice accumulation on autorotational descent performance. Further artificial icing tests should be conducted with an improved spray system to properly evaluate the effects of rotor blade ice accretion on autorotational descent performance of the CH-47C helicopter.

HANDLING QUALITIES

27. The handling qualities of the CH-47C helicopter in an artificial icing environment were evaluated in conjunction with other tests throughout the test program. Control positions were recorded for each icing segment prior to entering the spray cloud and again during tests conducted outside the cloud following ice accretion. In addition to the control position comparisons, qualitative pilot assessments were made with respect to the trimmability, stability, and controllability characteristics of the aircraft following ice accretion. The qualitative pilot comments and recorded control position data showed no apparent changes in the handling qualities of the helicopter with ice accumulation. Within the scope of this test, except for the degradation of handling qualities associated with increased vibration levels (para 18), the handling qualities of the CH-47C helicopter are not adversely affected by ice accumulation.

CONCLUSIONS

GENERAL

28. Within the scope of these tests, the CH-47C helicopter equipped with unprotected T55-L-11A engines does not possess the capability to safely operate in an icing environment. The following conclusions were also reached upon completion of the CH-47C helicopter artificial icing tests:

a. The most stable flight conditions for the test helicopter were observed to be at a standoff distance of approximately 110 feet. Stabilized flight at this distance could be achieved with minimal cyclic inputs and torque changes of ±2 percent (para 9).

b. If a quantitative measurement of rotor blade ice accretion is desired in future tests, a method of in-flight measurement must be devised or the ambient temperature must be low enough to permit ground measurement of ice accumulation (para 12).

c. An ice detection and accretion rate system is an enhancing feature for helicopters required to operate in icing conditions (para 13).

d. Asymmetrical rotor system ice loading significantly increased aircraft vibration levels at the pilot station (para 23).

e. Within the scope of these tests, the standard anti-ice systems functioned properly (para 24).

f. Significant increases in engine torque due to rotor system ice accumulation indicate a degradation of endurance and range can be expected (para 25).

g. Because of the limited nature of this test program and the spray system characteristics (inadequate vertical cloud thickness to totally immerse the test helicopter), a complete quantitative performance assessment and its effects on the CH-47C mission profile could not be determined (paras 25 and 26).

h. Within the scope of these tests, except for the degradation of handling qualities associated with increased vibration levels, the handling qualities of the CH-47C helicopter are not adversely affected by ice accumulation (para 27).

i. Two deficiencies and two shortcomings were identified.

DEFICIENCIES AND SHORTCOMINGS

29. The following deficiencies were identified:

a. Ice shedding from the rotor system, resulting in rotor blade damage caused by rotor blade and ice particle impact (para 16).

b. The ingestion of shed ice particles, which resulted in engine FOD (para 20).

30. The following shortcomings were identified:

a. Ice shedding from the rotor system, resulting in damage to the aft rotor head rain cover and the upper left engine oil cooler inlet (para 17).

b. The asymmetrical shedding of ice from the CH-47C rotor system, which results in moderate 1/rev lateral vibrations (para 18).

RECOMMENDATIONS

31. The deficiencies identified must be corrected prior to release of the CH-47C helicopter for flight in icing conditions or further tests in icing conditions (paras 16 and 20).

32. The shortcomings should be corrected (paras 17 and 18).

33. Following correction of the deficiencies, further tests, utilizing a modified HISS or other device which creates a spray cloud of sufficient size to totally immerse the test helicopter, should be conducted to completely evaluate operation of the CH-47C helicopter in an artificial icing environment (para 10).

34. Following correction of the deficiencies, icing severity tests should be conducted at lower temperatures (less than -8.5°C) to fully evaluate the flight characteristics of the CH-47C helicopter in artificial icing conditions (para 14).

35. A careful postflight inspection of the rotor blades should be made following flight in icing conditions (para 16).

36. The following CAUTION should be placed in chapter 10 of the operator's manual (para 16):

CAUTION

> Ice accumulated on rotor blades during flight in icing conditions may shed and impact blades of both rotor systems. This rotor blade impact with shed ice may cause sufficient damage to necessitate blade change. Following flight in icing conditions, all rotor blades should be carefully inspected, with particular attention directed to the lower skin surfaces of the blade.

37. If icing conditions are encountered, a careful postflight examination of the fuselage should be accomplished, with particular attention directed to the upper left side of the aft pylon (para 17).

38. The following NOTE should placed in chapter 10 of the operator's manual (para 17):

NOTE

> If icing conditions are encountered, ice shed from the rotor system may cause damage to the helicopter fuselage. A careful postflight examination of the fuselage, with particular attention directed to the upper left side of the aft pylon, should be accomplished.

39. The following WARNING should be placed in chapter 10 of the operator's manual (para 19).

WARNING

> During flight in icing conditions, asymmetrical ice shedding from the rotor system may result in moderate aircraft vibrations. Vigorous control activity may induce a more asymmetrical loading of ice on the rotor systems. Large control movements should not be made in an attempt to reduce the low-frequency aircraft vibrations caused by rotor system asymmetrical ice loading. These movements may induce a more asymmetrical ice loading of the rotor systems, further aggravating helicopter vibration levels.

40. Further testing of the CH-47C helicopter should not be conducted until engine inlet protection is provided to preclude ice FOD to the engines (para 20).

41. The CH-47C helicopter equipped with unprotected T55-L-11A engines should be restricted from flight into known or forecast icing conditions, and the following WARNING should be placed in chapter 10 of the operator's manual (para 20).

WARNING

> Significant engine FOD can be sustained by the unprotected T55-L-11A engines as a result of shed ice particle ingestion. The CH-47C helicopter equipped with unprotected T55-L-11A engines should not be flown in known or forecast icing conditions.

42. The following WARNING should be placed in chapter 10 of the operator's manual (para 21):

WARNING

> Following flight in icing conditions, ice shed from the rotor blades and/or other rotating components presents a hazard to personnel during ground operation and shutdown of the helicopter. Ground personnel should remain well clear of the helicopter during landing, ground operation, and shutdown. Passengers/crewmembers should not exit the aircraft until the rotor rotation has stopped.

43. Further artificial icing tests of the CH-47C helicopter should be conducted to thoroughly investigate prolonged icing of the SAS yaw ports and chin bubbles (para 24).

44. Further icing tests should be conducted to completely evaluate ice accretion effects on the level flight performance of the CH-47C helicopter (para 25).

45. Further artificial icing tests should be conducted with an improved spray system to properly evaluate the effects of rotor blade ice accretion on autorotational descent performance of the CH-47C helicopter (para 26).

APPENDIX A. REFERENCES

1. Letter, AVSCOM, AMSAV-EFT, 14 February 1973, subject: Army Heliconter Simulated Icing Tests, AVSCOM Test Request, Project No. 73-04.

2. Test Plan, USAASTA, Project No. 73-04, *Army Helicopter Artificial Icing Tests*, June 1973.

3. Technical Manual, TM 55-1520-227-10, *Operator's Manual, Army Model CH-47B and CH-47C Helicopters*, 3 August 1973.

4. Final Report, USAASTA, Project No. 72-35, *Helicopter Icing Spray System Qualification*, October 1973.

5. Technical Manual, All American Engineering Company, SM 280A, *Installation, Operation and Maintenance Instructions, Icing Conditions Simulation Equipment*, undated.

6. Message, AVSCOM, AMSAV-EFT, R081350Z April 1974, subject: Safety of Flight Release (SOFR) for CH-47C Artificial Icing Tests.

7. Final Report, USAASTA, Project No. 73-04-4, *Artificial Icing Tests, UH-1H Helicopter, Part I*, January 1974.

8. Final Report, USAAEFA, Project No. 73-04-2, *Artificial Icing Tests, AH-1G Helicopter*, under preparation.

9. Maintenance Manual, TM 55-1520-227-34-3, *Army Model CH-47B and CH-47C Helicopters*, 3 August 1973.

10. Equipment Performance Report, No. 73-04-1-2, "CH-47C Helicopter Artificial Icing Evaluation," 2 May 1974.

11. Equipment Performance Report, No. 73-04-1-1, "CH-47C Helicopter Artificial Icing Evaluation," 2 May 1974.

12. Military Specification, MIL-H-8501A, *Helicopter Flying and Ground Handling Qualities; General Requirements For*, 7 September 1961, amended 3 April 1962.

13. Technical Report, Rosemount Inc., No. 67312A, *A Discussion of Icing Rate Measurement and the Rosemount Icing Rate System*, undated.

14. Technical Report, Calspan Corporation, No. CG-5391-M-1, *Measurement of the Microphysical Properties of a Water Cloud Generated by an Airborne Spray System*, December 1973.

APPENDIX B.

CH-47C ICING SPRAY SYSTEM DESCRIPTION

The icing spray system equipment consists of a 75-foot spray boom, boom supports, boom hydraulic actuators, an 1800-gallon water tank, and spray system control equipment (fig. 1). Total weight of the system without water is 4700 pounds. The icing spray boom is located in a horizontal plane 15 feet below the aircraft during operation and can be jettisoned in flight. The LWC and droplet size distribution can be changed by varying the water flow rate and air pressure with the spray system control equipment mounted inside the CH-47C aircraft. The spray cloud calibration was initially conducted by the Forge Aerospace Corporation in July 1973 at Edwards Air Force Base, and additional calibration data were provided by Calspan Corporation in September 1973 at Fort Wainwright, Alaska. Detailed spray system characteristics are contained in references 4 and 5, appendix A.

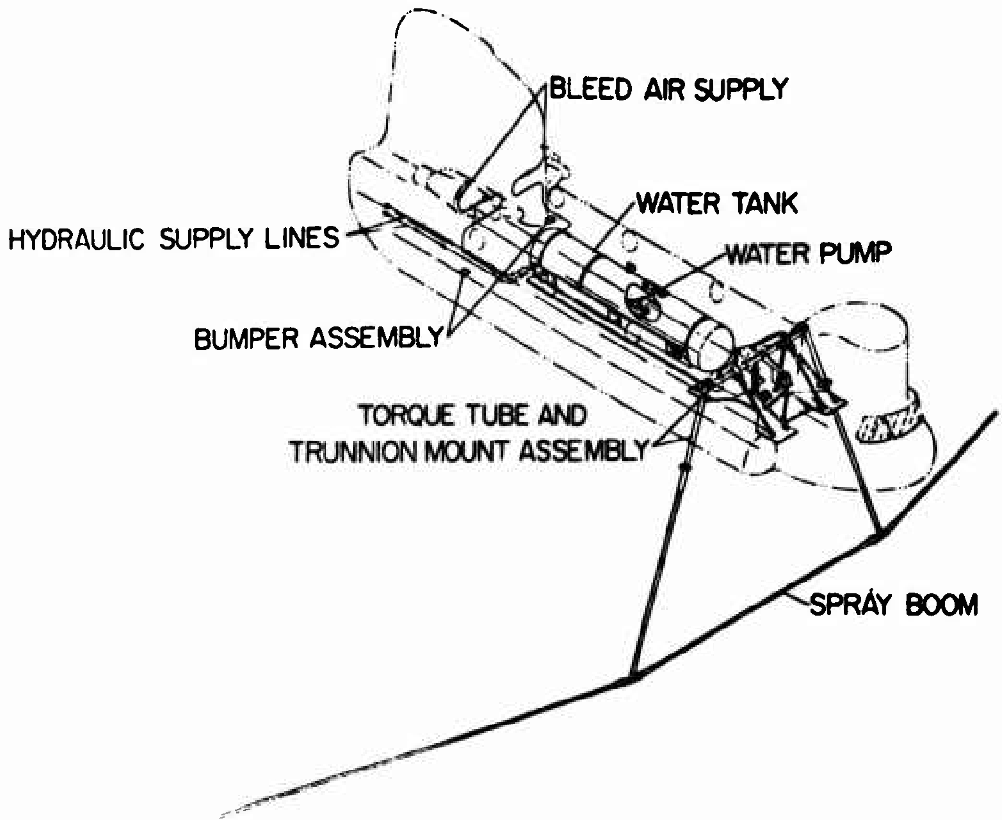


Figure 1. Helicopter Icing Spray System Schematic.

APPENDIX C.

INSTRUMENTATION AND SPECIAL EQUIPMENT

INSTRUMENTATION

Photopanel

1. A photopanel was used to record selected parameters on 35mm film (photos 1 and 2). A film rate of one frame per second was used. The following parameters were recorded:

Airspeed (ship's system)
Altitude (ship's system)
Engine output shaft torque (both engines)
Gas producer turbine speed (N_1) (both engines)
Exhaust gas temperature (both engines)
Main rotor speed
Vertical speed
Total air temperature
Fuel counter and flow rates (both engines)
Time
Frame counter
Event lights
Thrust control position
Lateral cyclic control position
Longitudinal cyclic control position
Directional control position

Magnetic Tape System

2. An Ampex Model AR700 1-inch magnetic tape recorder was installed and is shown in photo 3. Vertical, lateral, and longitudinal vibrations were recorded at the pilot station (photo 4), the aft rotor transmission area (photo 5), and the forward rotor transmission area. The Rosemount icing severity signal and the Rosemount ice accretion signal were also recorded on magnetic tape.

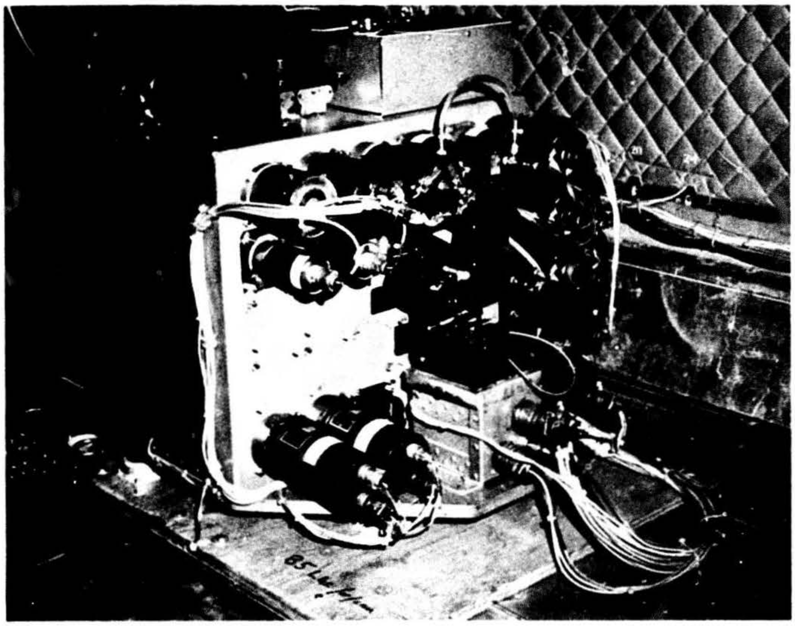


Photo 1. CH-47C Photopanel Installation.

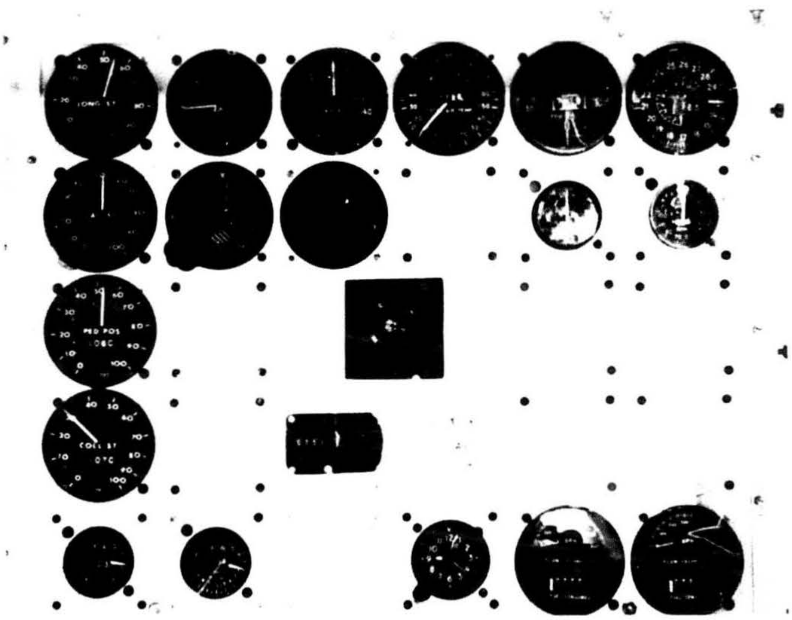


Photo 2. Photopanel Instrument Arrangement.

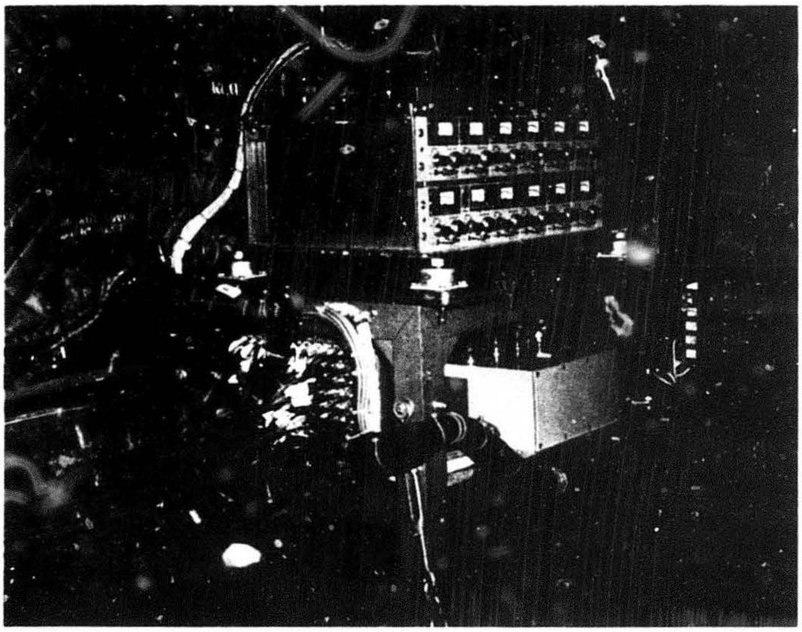


Photo 3. Magnetic Tape System Installation.

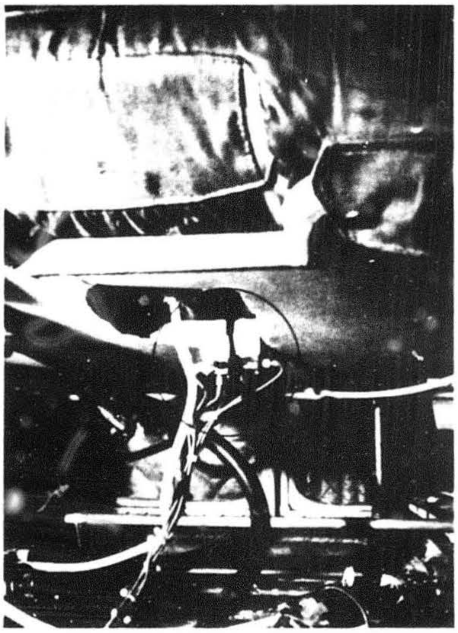


Photo 4. Pilot Seat Pad Accelerometer Installation.

Photo 5. Transmission Area Accelerometer Installation.

Miscellaneous Instrumentation

3. Outside air temperature was measured using a Rosemount sensitive total temperature measuring system (photo 6). Cockpit communications were recorded with a small portable cassette tape recorder as well as with the magnetic tape data system. The instrumentation controls and indicators are shown in photos 7, 8, and 9.

SPECIAL EQUIPMENT

Ice Accretion Indicator Probe

4. An ice accretion indicator probe was designed, fabricated, and mounted on the test aircraft by USAAEFA personnel and was used to give the pilot a visual cue to ice buildup on the fuselage of the helicopter. The probe consists of a small symmetrical airfoil (OH-6A tail rotor section) with a 3/16-inch diameter steel rod protruding 1-1/2 inches outward from the center of the airfoil leading edge (photo 10). The unit was mounted above the copilot's overhead window and was visible to the copilot during all tests. The protruding rod was masked with 1/4-inch graduations of contrasting colors which provided a method of quantitatively measuring the ice buildup on the leading edge of the airfoil.

Photo 6. Total Temperature Probe Installation.

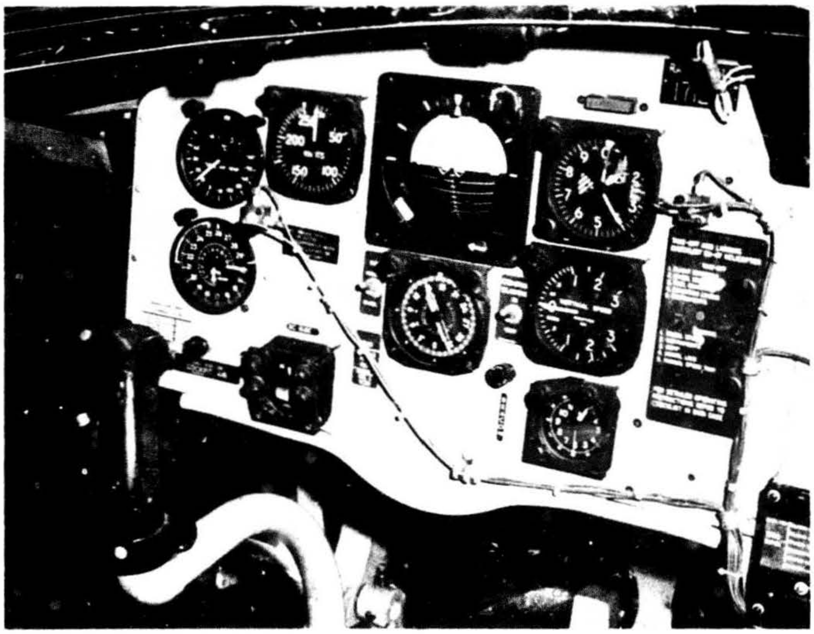


Photo 7. Copilot Panel Instrumentation Arrangement.

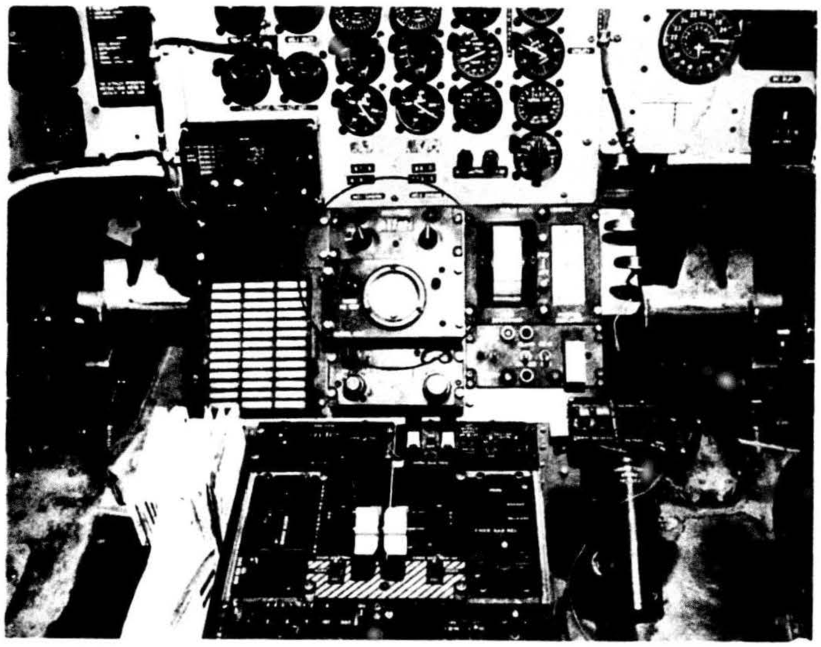


Photo 8. Rosemount Icing Rate Indicator Installation.

Photo 9. Instrumentation Control Installation.

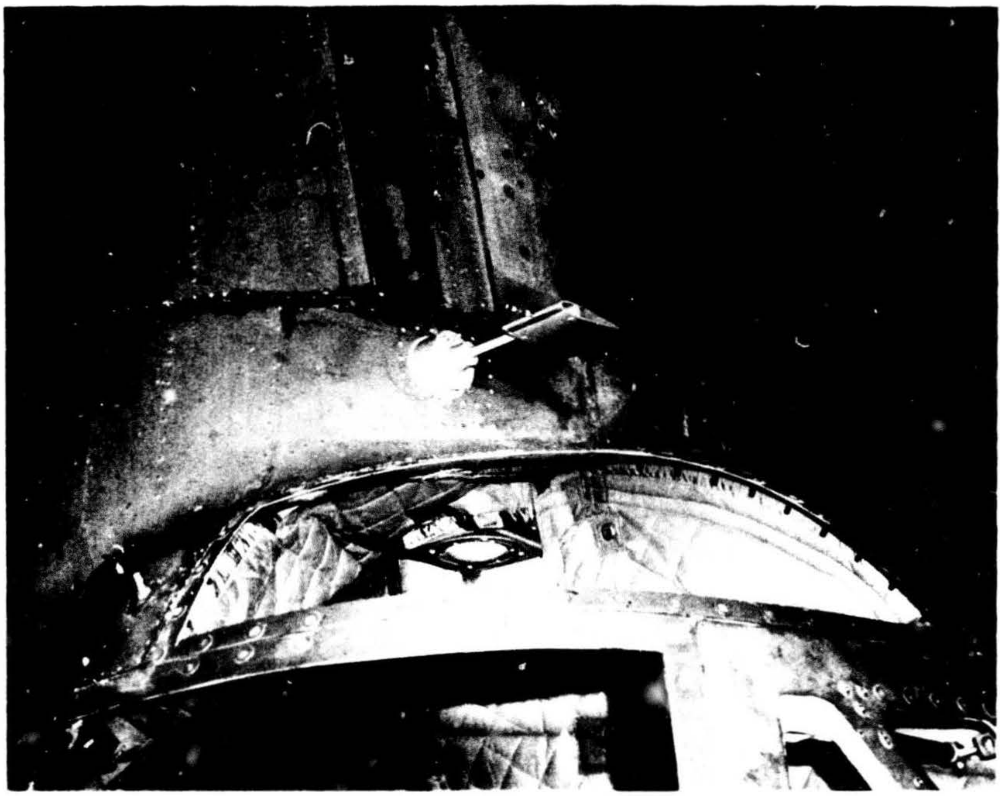


Photo 10. Visual Ice Accretion Probe Installation.

Ice Detection and Accretion Rate System

5. A Rosemount ice detection and accretion rate system was used to quantify icing rate and accretion while in the icing environment. The system consisted of a probe (Model 871FA) mounted on the right side of the forward pylon (photo 11), a cockpit indicator (Model 512P) (photo 8), and an analog output which was recorded on the magnetic tape data system.

6. The sensing element of the Rosemount ice detector is a tube that vibrates axially at a resonant frequency of approximately 40 kilohertz. Axial vibration is achieved by magnetostriction and amplitudes are on the order of microinches. When ice forms on the sensing element, a change in resonant frequency occurs. The frequency change is noted by comparison with a fixed-frequency oscillator and the rate of frequency change is used to determine icing rate. Visual readout is from a meter calibrated for trace, light, moderate, and heavy icing rates (photo 8). A complete system description and theory of operation is contained in reference 13, appendix A. An airspeed compensation system was devised by USAAEFA personnel to adjust the icing rate system to the proper sensitivity for the true airspeed being flown. A true airspeed computation was made prior to entry into the icing environment based on temperature, altitude, and indicated airspeed. This airspeed was related to an external resistance which compensated the icing rate system sensitivity to the selected true airspeed (photo 9). The Rosemount icing rate system installed on the test aircraft was wind tunnel-calibrated by the manufacturer. Table 1 contains the information supplied to USAAEFA to cross-reference display indications with LWC.

Table 1. Rosemount Icing Rate System Wind Tunnel Liquid Water Content Calibration.[1]

Meter Indication	Measured Liquid Water Content (gram/meter^3)
T (trace)	0.09
L (light)	0.16
M (moderate)	0.29
H (heavy)	0.60

[1]Calibration for icing rate system, Model 512P, SN 4.

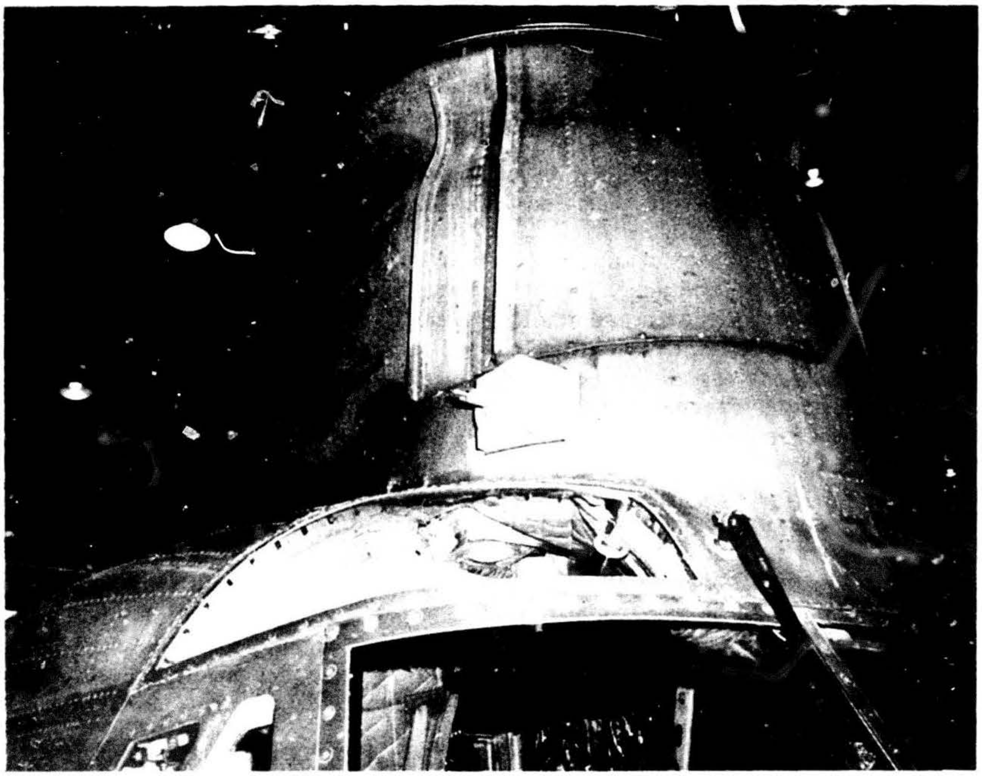


Photo 11. Rosemount Ice Detector Probe Installation.

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

TEST TECHNIQUES

1. The following procedure was used to accumulate ice on the airframe and rotor systems of the test aircraft. All standard anti-ice systems were activated prior to entering the spray cloud. The test helicopter entered the spray cloud from below at a distance of 100 to 150 feet behind the spray aircraft. Icing was accomplished by positioning either the forward rotor system, aft rotor system, or fuselage in the spray cloud for a specific time interval at a programmed LWC and test temperature. After the icing time interval had elapsed, the test aircraft was maneuvered to a position clear of the spray cloud to conduct specific engineering tests. All test instrumentation was activated to record static conditions before and after ice accumulation. Spray aircraft to test aircraft separation distance was maintained during icing flight with information obtained from a radar system located in the spray aircraft. Separation distance was monitored and the information relayed to the test aircraft pilot by radio.

2. Fuselage ice accretion was measured in flight using the visual ice accretion indicator probe. Predetermined maximum permissible accretion levels were established for each flight in accordance with an established build-up program. The visual probe was monitored by the copilot during flight in the icing cloud to ensure that the desired accretion level was not exceeded and to obtain quantitative accretion data. The copilot also monitored the icing rate indication with the Rosemount ice detection and accretion rate system. Ice accretion was further documented with high-speed motion picture photography. In-flight film coverage of the test aircraft was accomplished using hand-held cameras operated from the chase aircraft or the spray aircraft. Ice remaining on the helicopter upon landing was measured at specific locations and was further documented with still photography.

3. Sublimation and shedding of ice often occurred in flight and reicing was required in order to investigate the effects of specific amounts of ice accumulation. Ice shedding characteristics were observed by personnel in the test, spray, and chase aircraft and were documented in several instances with high-speed motion picture photography.

4. Test airspeeds were established with the calibrated airspeed system of the spray aircraft. Outside air temperature and pressure altitude were hand-recorded in the spray aircraft. Water flow rate and bleed air pressure were established by instrumentation on board the spray aircraft and were also hand-recorded.

5. Level flight performance was evaluated by comparing engine torque requirements before and after ice accretion on the rotor systems. Base-line engine torque data were recorded outside the cloud prior to ice accumulation. Following specified periods of icing exposure, the aircraft was again stabilized at the same airspeed and the change in engine torque due to ice accumulation was recorded.

6. Autorotational descent performance was evaluated at the operator's manual recommended airspeed for minimum rate of descent to determine autorotational rotor speed limitations with ice buildup on the rotor blades. Base-line autorotational descent data were recorded with no rotor system ice accumulation. Following specified periods of icing exposure, autorotational data were again recorded in stabilized autorotation at the same airspeed and the ability to maintain autorotational rotor speed was evaluated.

7. The effects of ice accretion on handling qualities were evaluated by comparing control positions recorded in stabilized level flight at the airspeed used to accrete ice on the rotor system both before and after ice accumulation. Control position comparisons were also made by analyzing data recorded in stabilized autorotation at the operator's manual recommended airspeed for minimum rate of descent both before and after rotor system icing. In addition to the control position evaluations, qualitative pilot comments with respect to aircraft trimmability, stability, and controllability characteristics were compared at similar conditions before and after ice accretion.

8. Total temperature and frost point information were available on the spray aircraft. Total temperature was corrected to static conditions using the following equations.

$$T = \frac{T_o}{1 + (K - 1)\frac{M^2}{2}} \tag{1}$$

$$a = \sqrt{Kg\ R\ T} \tag{2}$$

$$M = \frac{V_t}{a} \tag{3}$$

Where:

T_o = Total temperature, °K

T = Static temperature, °K

K = Ratio of specific heat; 1.4 for air

g = Gravity acceleration

M = Mach number

a = Local speed of sound

R = Gas constant; 53.3 for air

V_t = Velocity true airspeed (TAS)

Frost point, obtained by utilizing a Cambridge thermoelectric dew point hygrometer, was corrected to dew point conditions by a conversion table printed in the instrument manufacturer's manual. Relative humidity was then computed using a saturation vapor pressure over water table published by the Smithsonian Institute. The percentage of spray cloud evaporation was computed using an empirical equation recommended by Calspan Corporation, following a calibration effort conducted in September 1973 (ref 14, app A). The following equation was used to compute the temperature and relative humidity related evaporation effects.

$$\text{Decay LWC (\% per second)} = \frac{10G}{G_o} \frac{(100 - Rh)}{45} \tag{4}$$

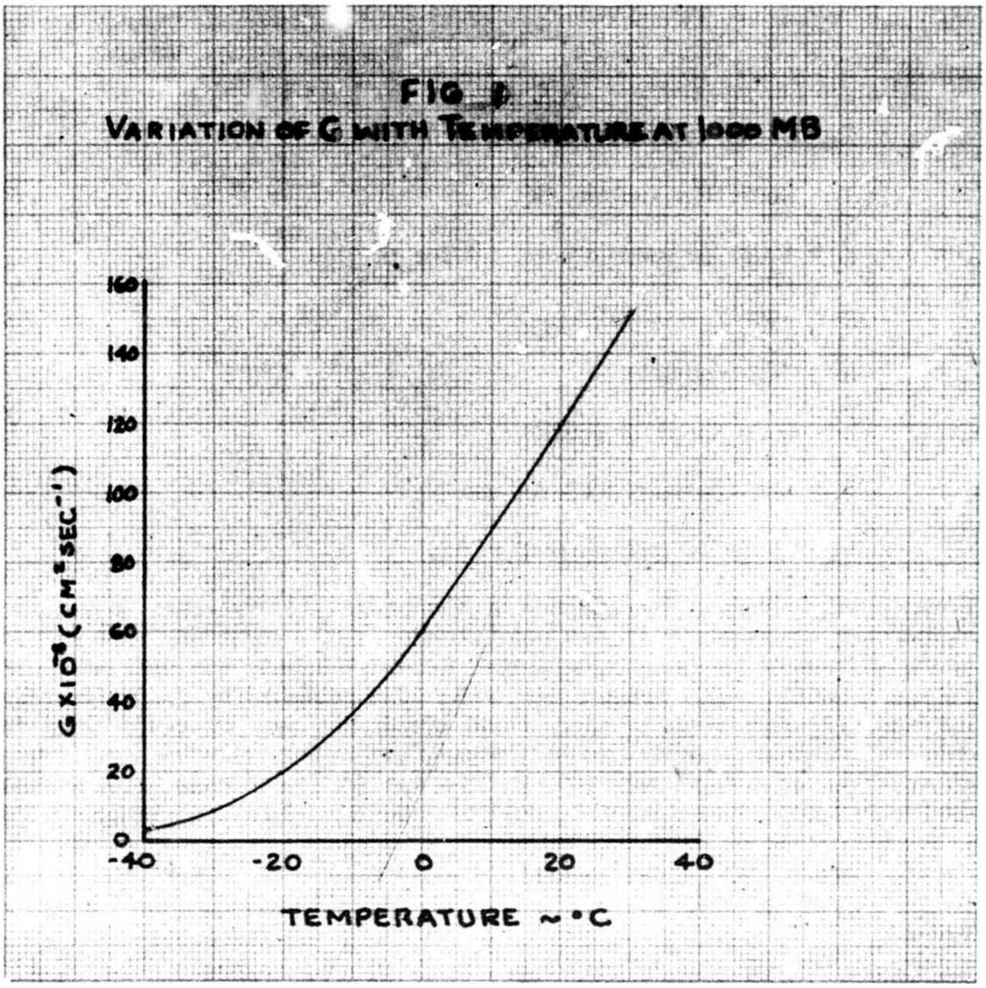
Where:

G = Thermodynamic function for applicable temperature (fig. 1)

$G_o = 60 \times 10^{-8}\ cm^2\ sec^{-1}$

Rh = Relative humidity

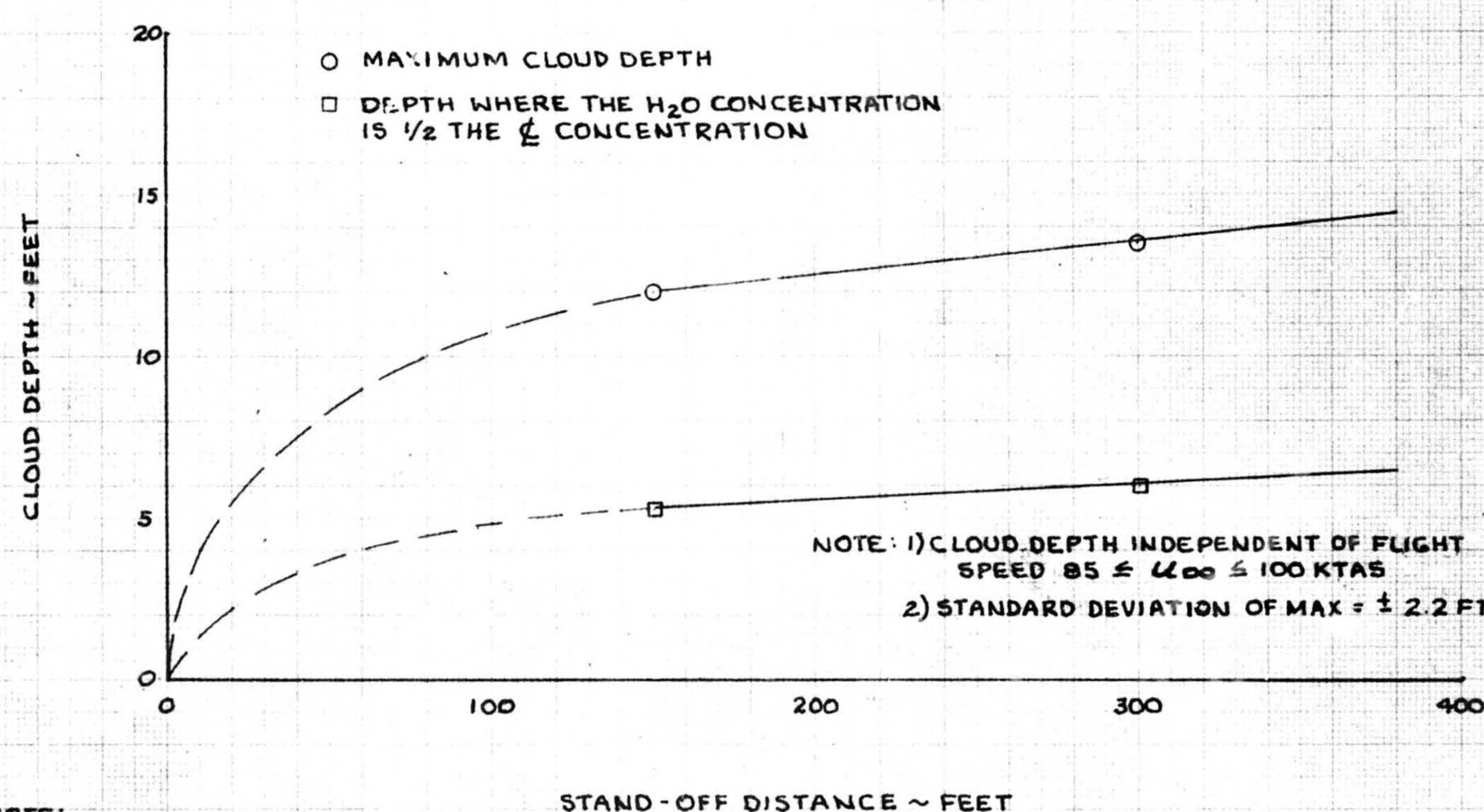
A corresponding increase in water flow rate adjusted the spray cloud to the proper LWC for a given ambient temperature and relative humidity.



Information furnished by the manufacturer of the icing spray system concerning cloud depth at various standoff distances is shown in figure 2. This information and the geometry of the spray boom were used to compute and construct a flow rate versus corrected LWC graph utilizing the conservation of mass principle. The results of this computation are shown in figure 3. The flow rate established from the above computations and a constant bleed air pressure of 15 psig were used to control the spray cloud test environment.

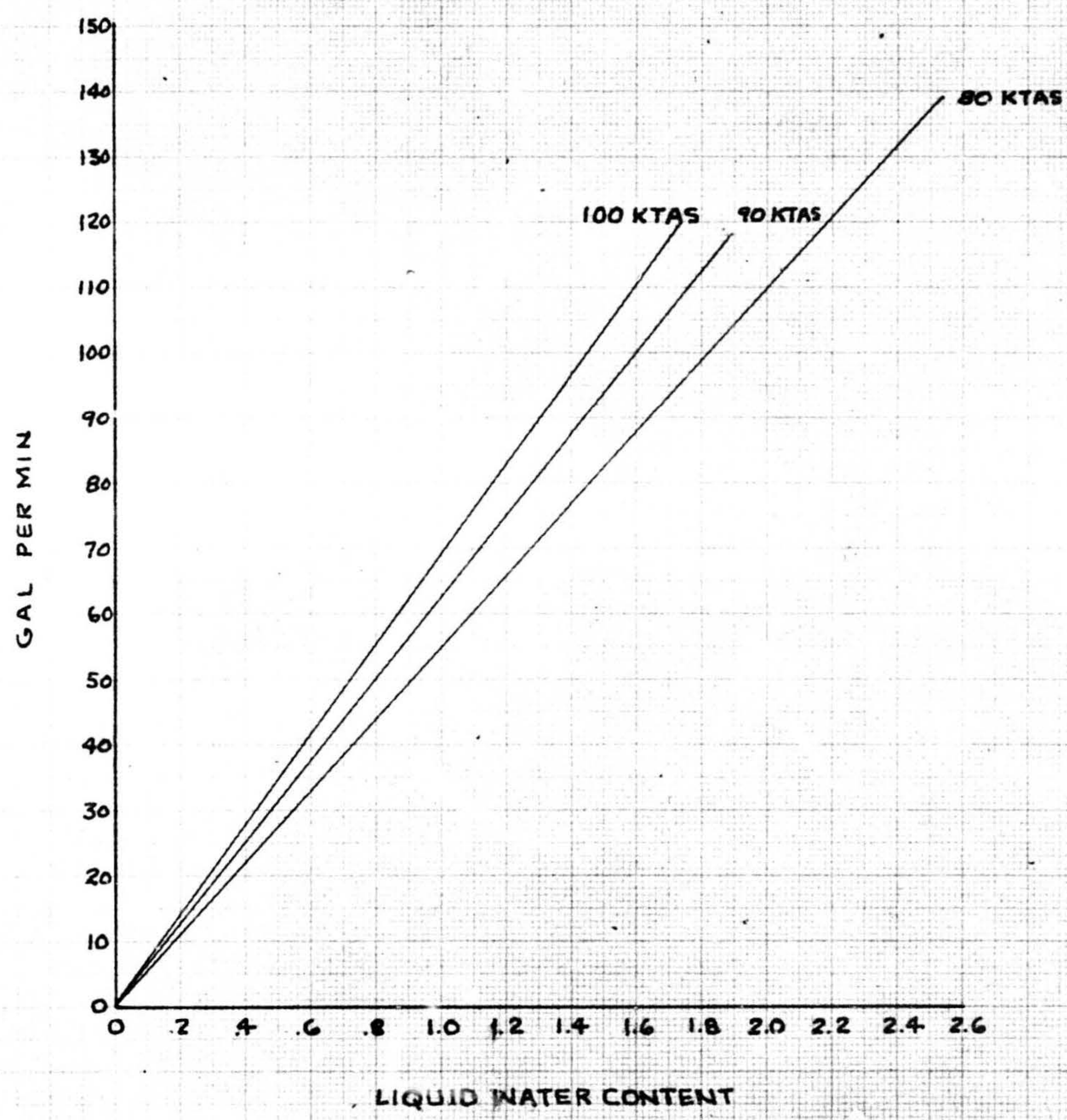
FIG 2

VARIATION OF CLOUD DEPTH WITH STAND-OFF DISTANCE



NOTE:
℄ = CENTER LINE
U_∞ = TRUE VELOCITY

FIG 3
FLOW RATE TO CORRECTED LIQUID WATER CONTENT CONVERSION
80, 90, 100 KTAS
150 FOOT STAND-OFF
NO EVAPORATION
OR CORRECTED LWC



DATA ANALYSIS METHODS

9. Icing severity was determined for each test flight by comparing data obtained from the Rosemount ice detection and accretion rate system with actual ice accretions in conjunction with icing definitions listed in paragraph 15. Ice accretion was measured in flight using the visual probe and high-speed photographic coverage. Additionally, postflight ice levels were measured immediately upon landing when practicable.

10. Ice shedding characteristics were qualitatively assessed by flight test personnel in the test, spray, and chase aircraft. High-speed motion picture films were used to quantify ice shedding characteristics on several flights.

11. Vibration levels were qualitatively assessed by the pilot of the test aircraft and quantitative vibration data were recorded on a magnetic tape data system. A Spectral Dynamics 301 real time spectral analyzer was utilized to convert the data from the time domain (acceleration as a function of time) to the frequency domain (acceleration as a function of frequency). The output of the spectral analysis was a plot of acceleration versus frequency, composed of acceleration values at 500 discrete frequencies uniformly spaced over the selected frequency range.

12. Level flight performance degradation due to ice accretion was assessed by comparing the engine torque required to maintain constant airspeed and altitude before and after rotor system ice accumulation.

13. Autorotational descent performance degradation due to ice accretion was evaluated by comparing the stabilized autorotational rotor speed which could be attained before and after ice accumulation on the rotor system.

14. The effect of ice accretion on the test aircraft handling qualities was qualitatively assessed by the pilot. An HQRS was used to augment pilot comments and is presented as figure 4. Control positions were quantitatively measured and comparisons made between no-ice base-line data and data recorded after ice accretion.

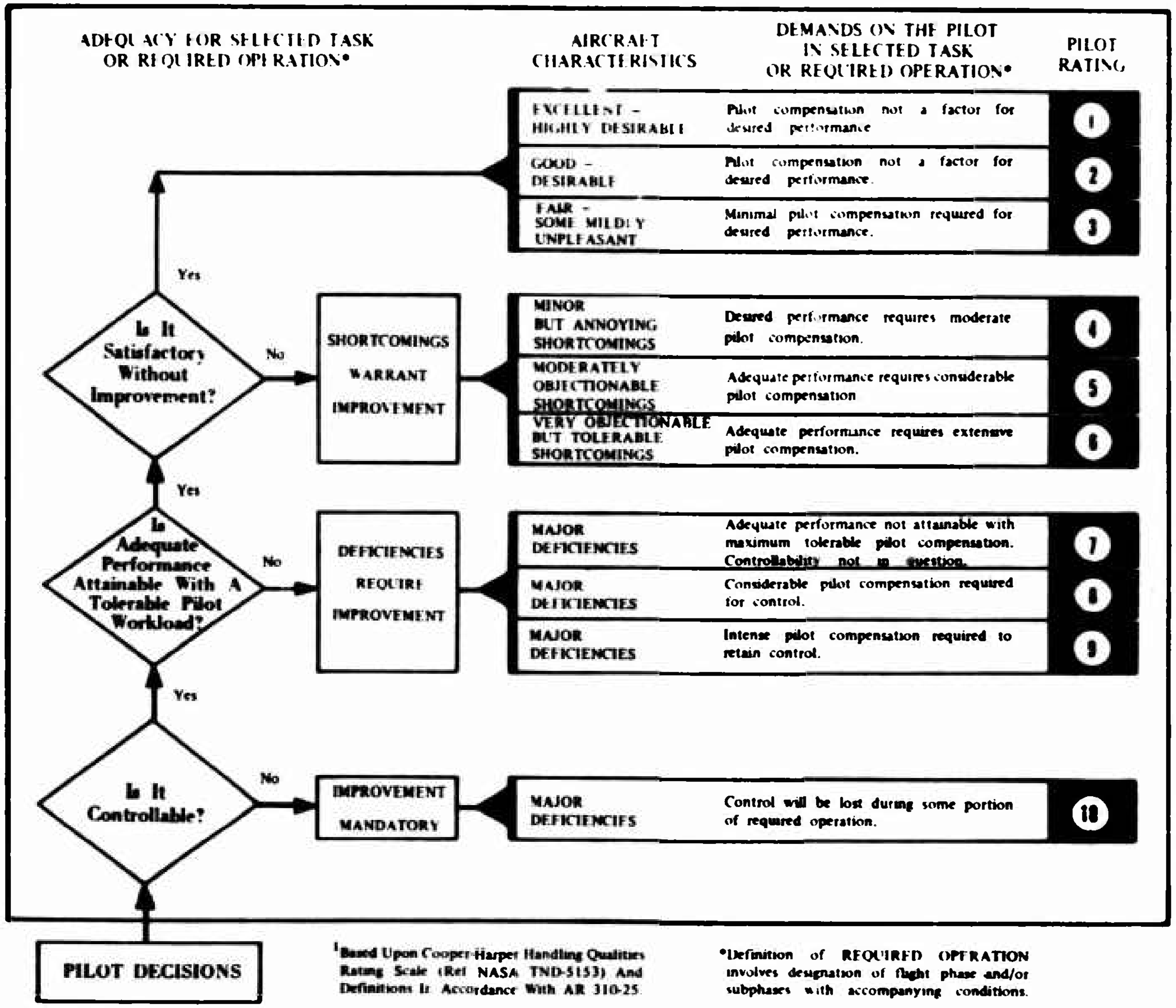


Figure 4. Handling Qualities Rating Scale.

15. Icing characteristics were described using the following definitions of icing types and severity:

a. Icing type definitions:

(1) Rime ice: An opaque ice formed by the instantaneous freezing of small supercooled droplets.

(2) Clear ice: A semitransparent ice formed by the slower freezing of larger supercooled droplets.

(3) Glime ice: A mixture of clear ice and rime ice which is very common.

b. Icing severity definitions:

(1) Trace icing: Accumulation of 1/2 inch of ice on a small probe each 80 miles. The presence of ice on the airframe is perceptible but the rate of accretion is nearly balanced by the rate of sublimation. Therefore, this is not a hazard unless encountered for an extended period of time. The use of deicing equipment is unnecessary.

(2) Light icing: Accumulation of 1/2 inch of ice on a small probe each 40 miles. The rate of accretion is sufficient to create a hazard if flight is prolonged in these conditions but insufficient to make diversionary action necessary. Occasional use of deicing equipment may be necessary.

(3) Moderate icing: Accumulation of 1/2 inch of ice on a small probe each 20 miles. On the airframe, the rate of accretion is excessive, making even short encounters under these conditions hazardous. Immediate diversion is necessary or use of deicing equipment is mandatory.

(4) Heavy icing: Accumulation of 1/2 inch of ice on a small probe each 10 miles. Under these conditions, deicing equipment fails to reduce or control the hazard and immediate exit from the icing condition is mandatory.

16. A range of values of LWC can generally be associated with each icing severity condition. Table 1 reflects these conditions.

Table 1. Liquid Water Content.

Icing Condition	Liquid Water Content[1] (gram/meter^3)
Trace	Zero to 0.1
Light	0.1 to 0.5
Moderate	0.5 to 1.0
Heavy	Greater than 1.0

[1]Based on a mean droplet size of 25 microns.

APPENDIX E. TEST DATA

FIG I

MIL-H-8501 A CREW STATION VIBRATION LIMITS

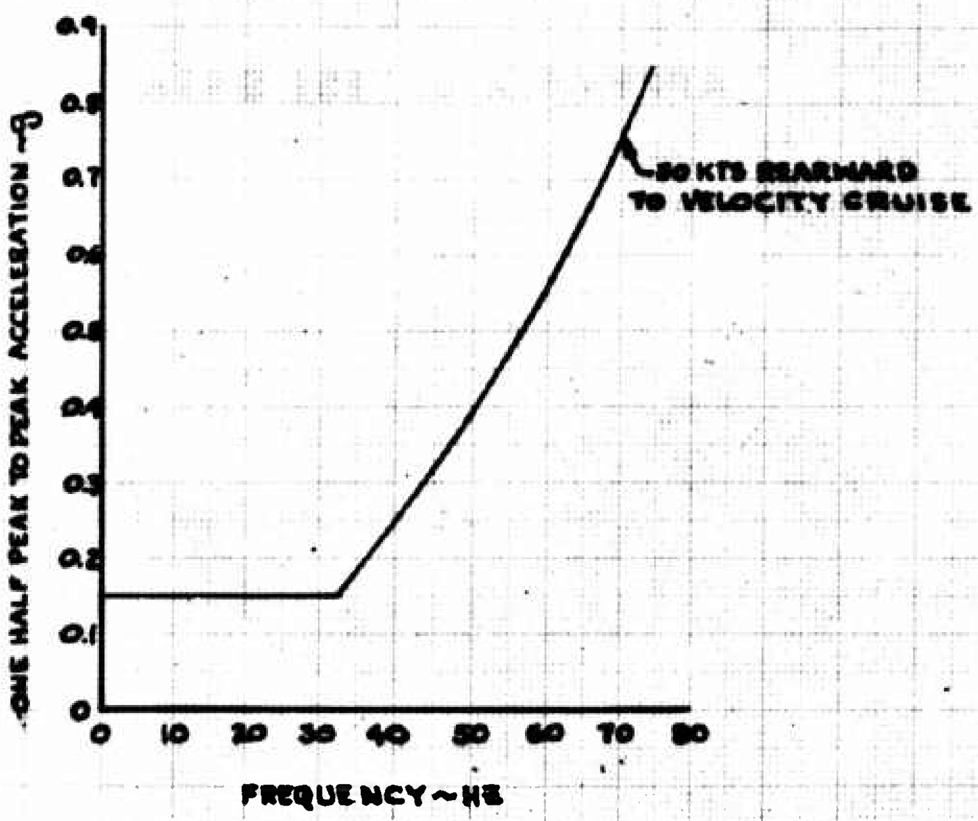


FIG 2

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 69-17126

FLIGHT 5

PILOT SEAT VERTICAL

TRIM NO ICE

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28,100	334.0	10,840	235	98	0.005332	LEVEL FLIGHT

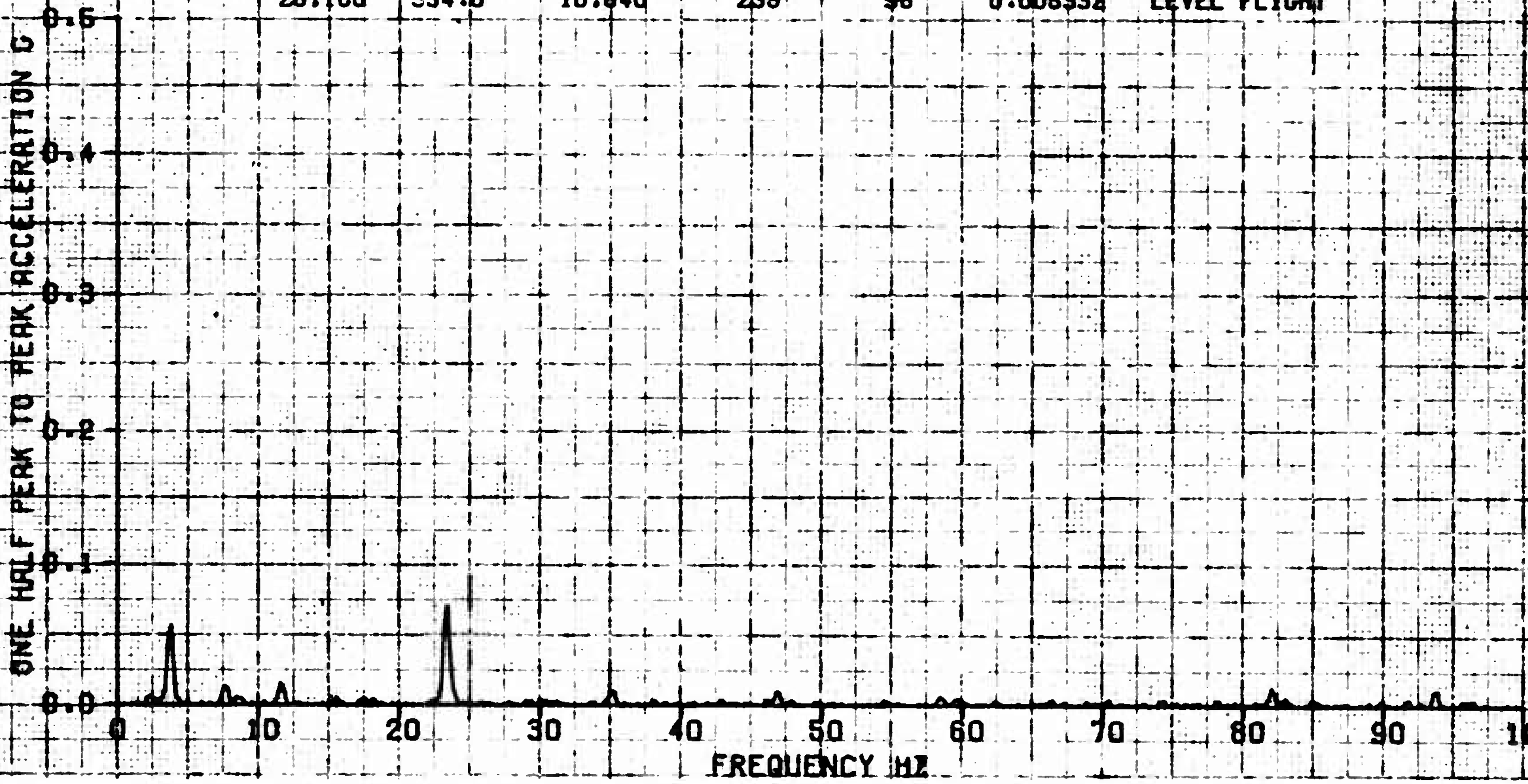


FIG 3

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 69-17126

FLIGHT 5

PILOT SEAT VERTICAL

IN ICING CLOUD PRIOR TO FIRST ASYMMETRIC ICE SHED

AVG. GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28,100	334.0	10,840	235	90	0.005332	LEVEL FLIGHT

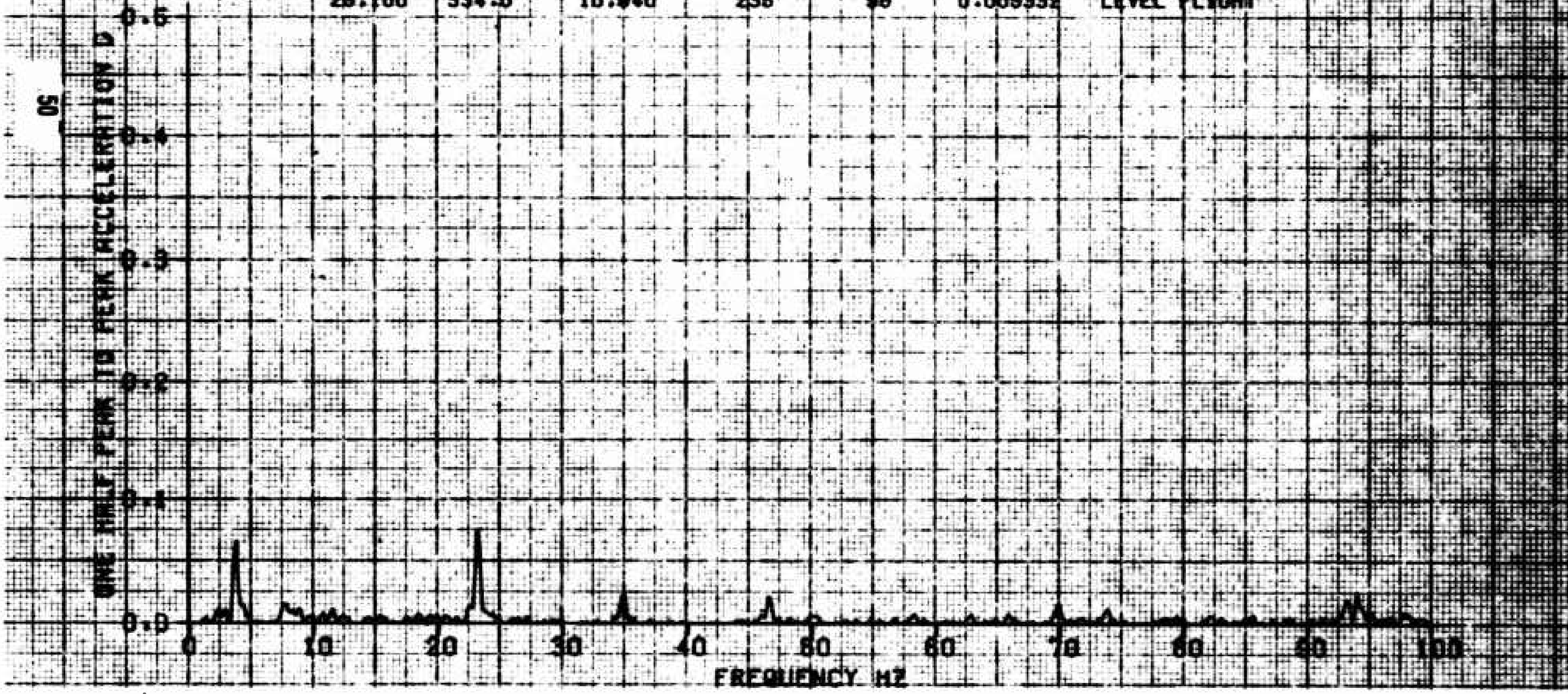


FIG 4
VIBRATION CHARACTERISTICS
ARTIFICIAL ICING TESTS
CH-47C USA S/N 69-17126
FLIGHT 5
PILOT SEAT VERTICAL
FIRST ASYMMETRIC ICE SHED

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28,100	334.0	10,840	235	98	0.006332	LEVEL FLIGHT

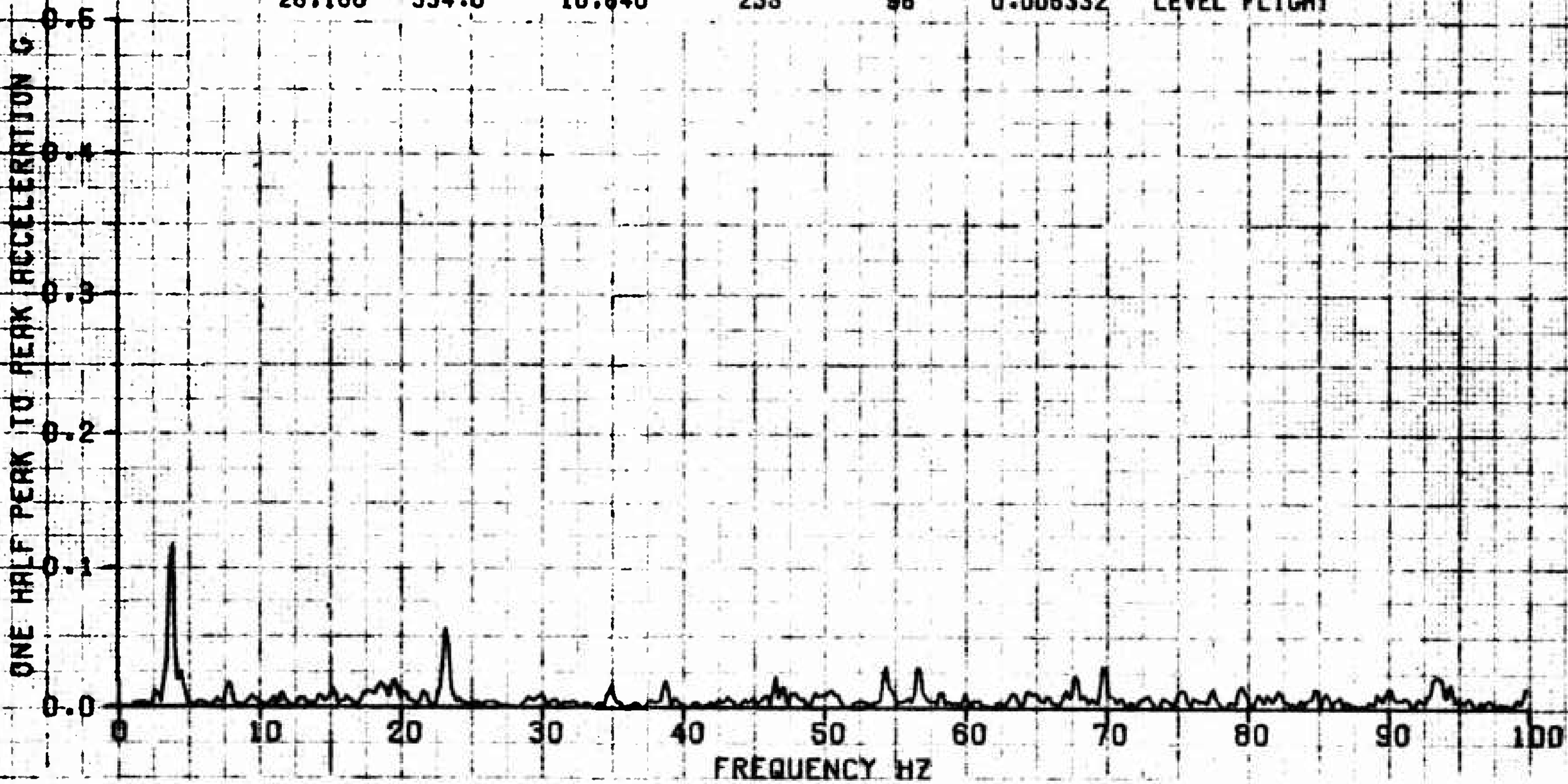


FIG 5

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 69-17126

FLIGHT 5

PILOT SEAT VERTICAL

AFTER FIRST ASYMMETRIC ICE SHED RETURNED TO NORMAL

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28,100	334.0	10,840	235	98	0.006332	LEVEL FLIGHT

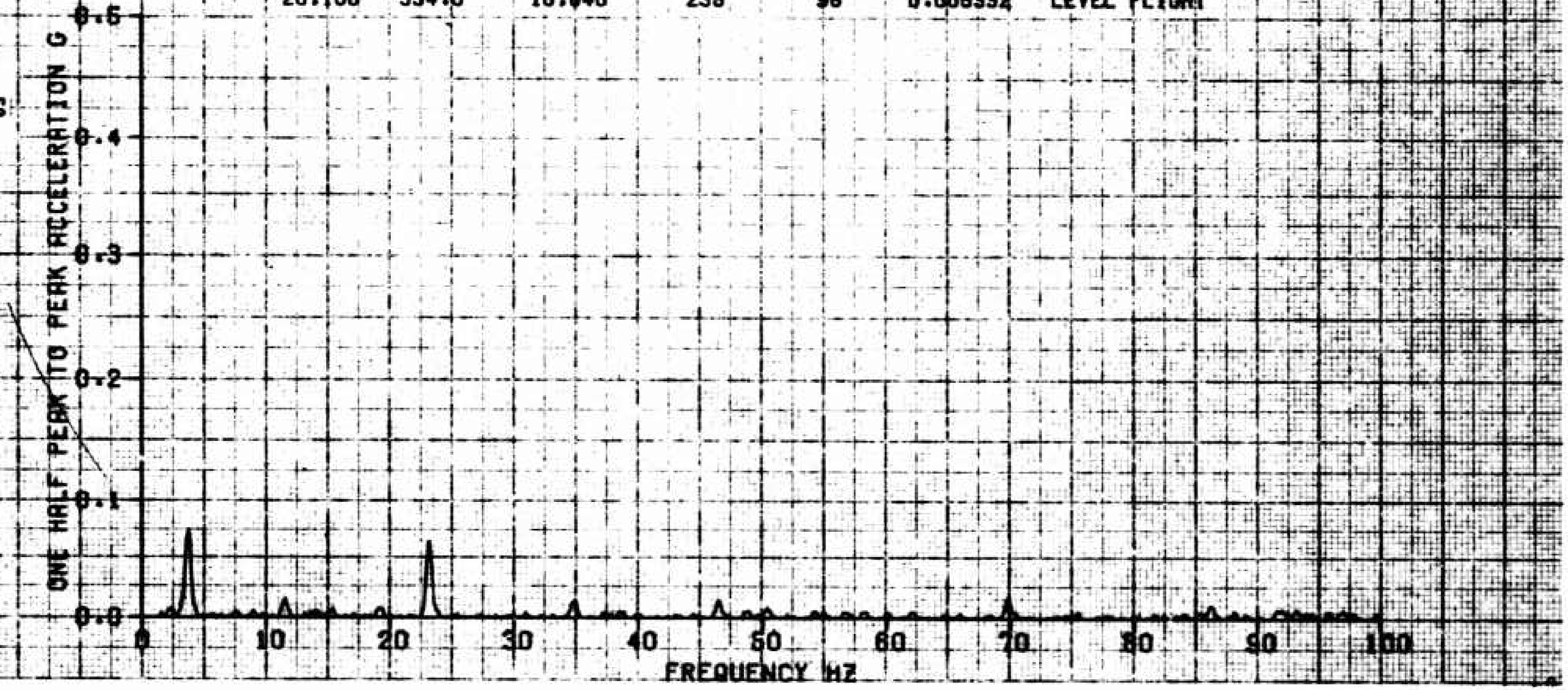


FIG 6

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 69-17126

FLIGHT 5

PILOT SEAT VERTICAL

IN ICING CLOUD PRIOR TO SECOND ASYMMETRIC ICE SHED

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28.100	334.0	10.840	235	98	0.006332	LEVEL FLIGHT

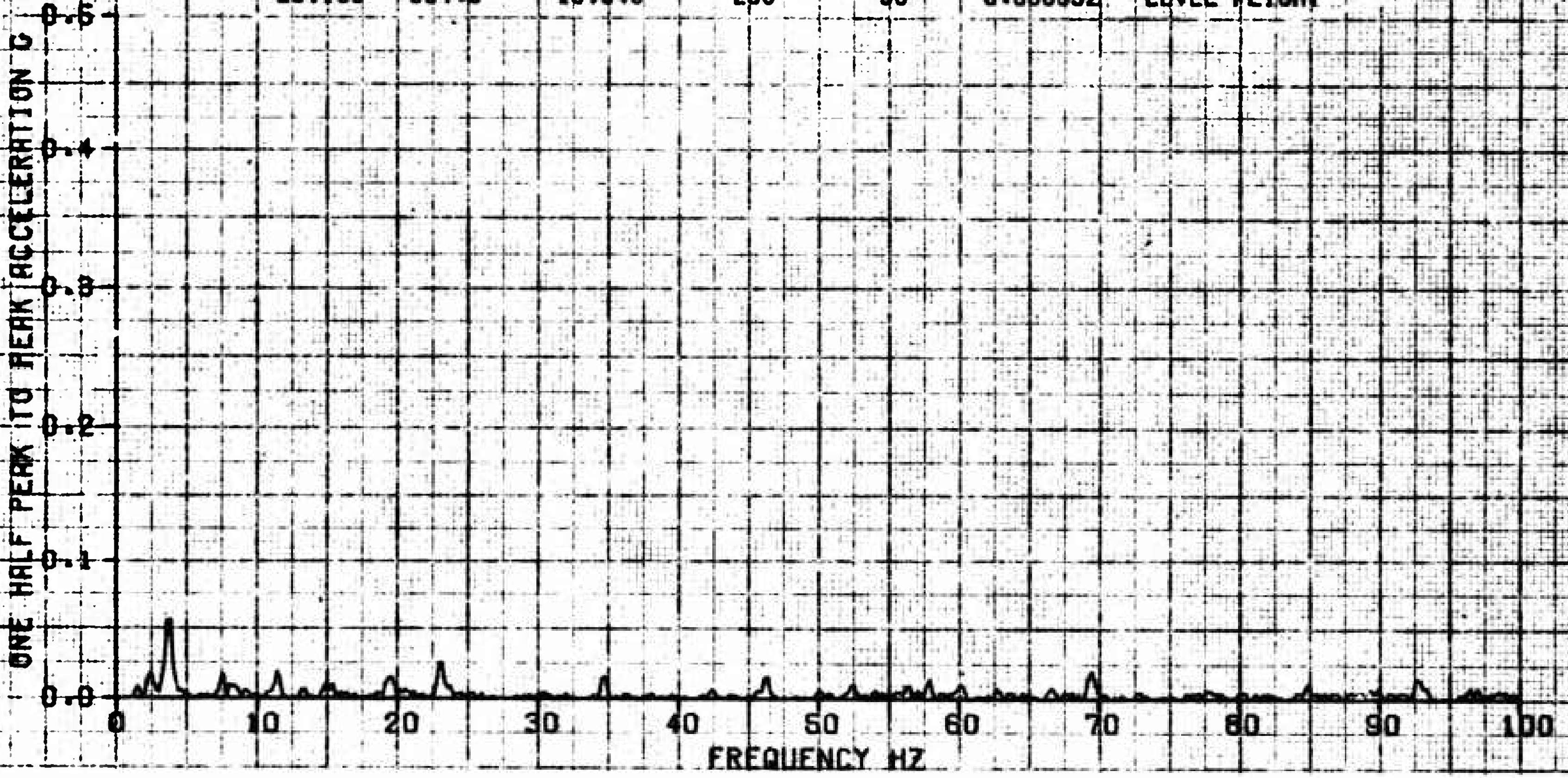


FIG 7
VIBRATION CHARACTERISTICS
ARTIFICIAL ICING TESTS
CH-47C USA S/N 69-17126
FLIGHT 5
PILOT SEAT VERTICAL
SECOND ASYMMETRIC ICE SHED

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28.100	334.0	10.840	236	98	0.005332	LEVEL FLIGHT

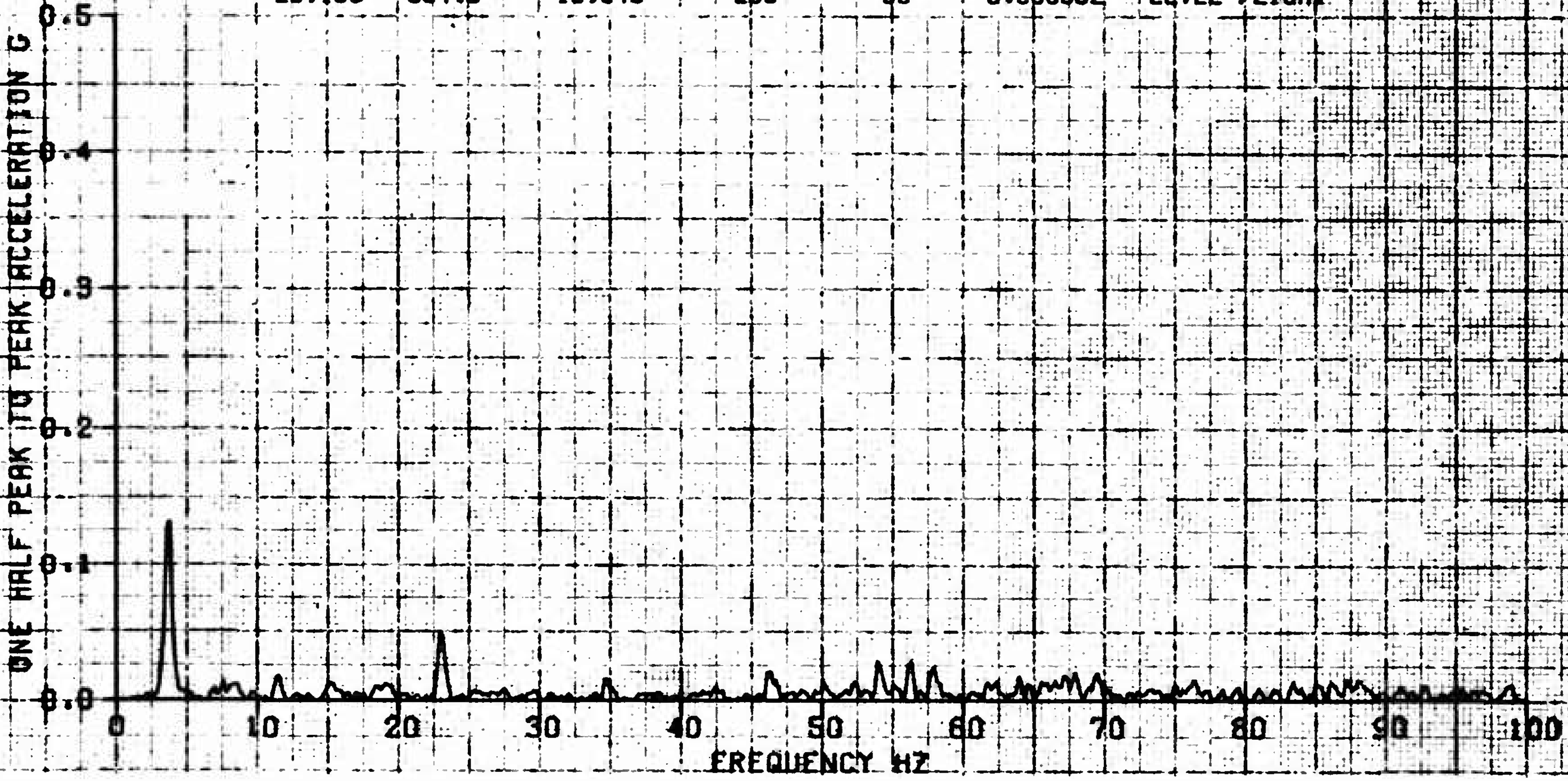


FIG 8

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 69-17126

FLIGHT 5

PILOT SEAT VERTICAL

AFTER SECOND ASYMMETRIC ICE SHED RETURNED TO NORMAL

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28,100	334.0	10,840	235	98	0.006332	LEVEL FLIGHT

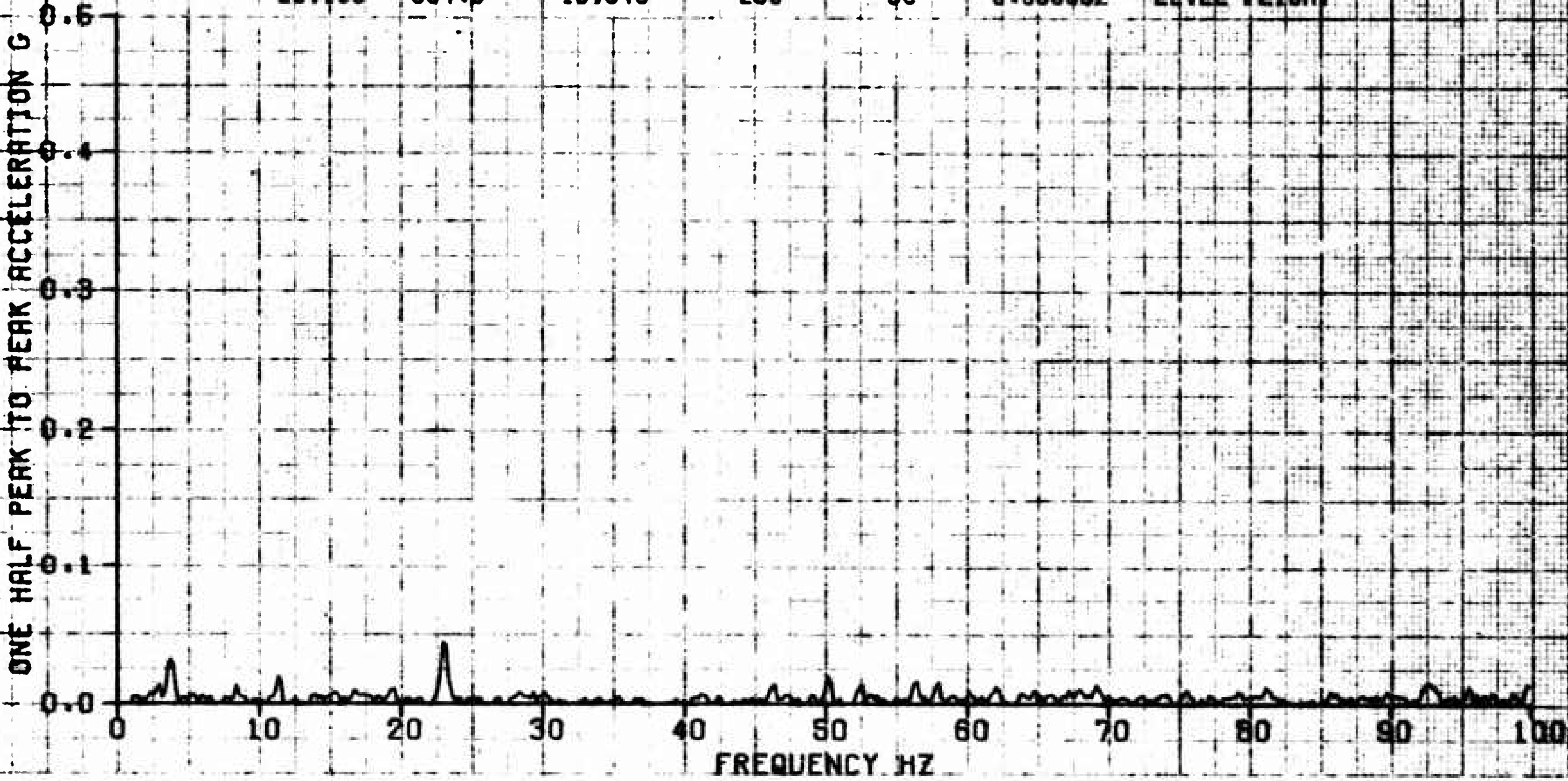


FIG 9

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 69-17126

FLIGHT 5

PILOT SEAT LATERAL

TRIM NO ICE

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28.100	334.0	10.840	235	98	0.005332	LEVEL FLIGHT

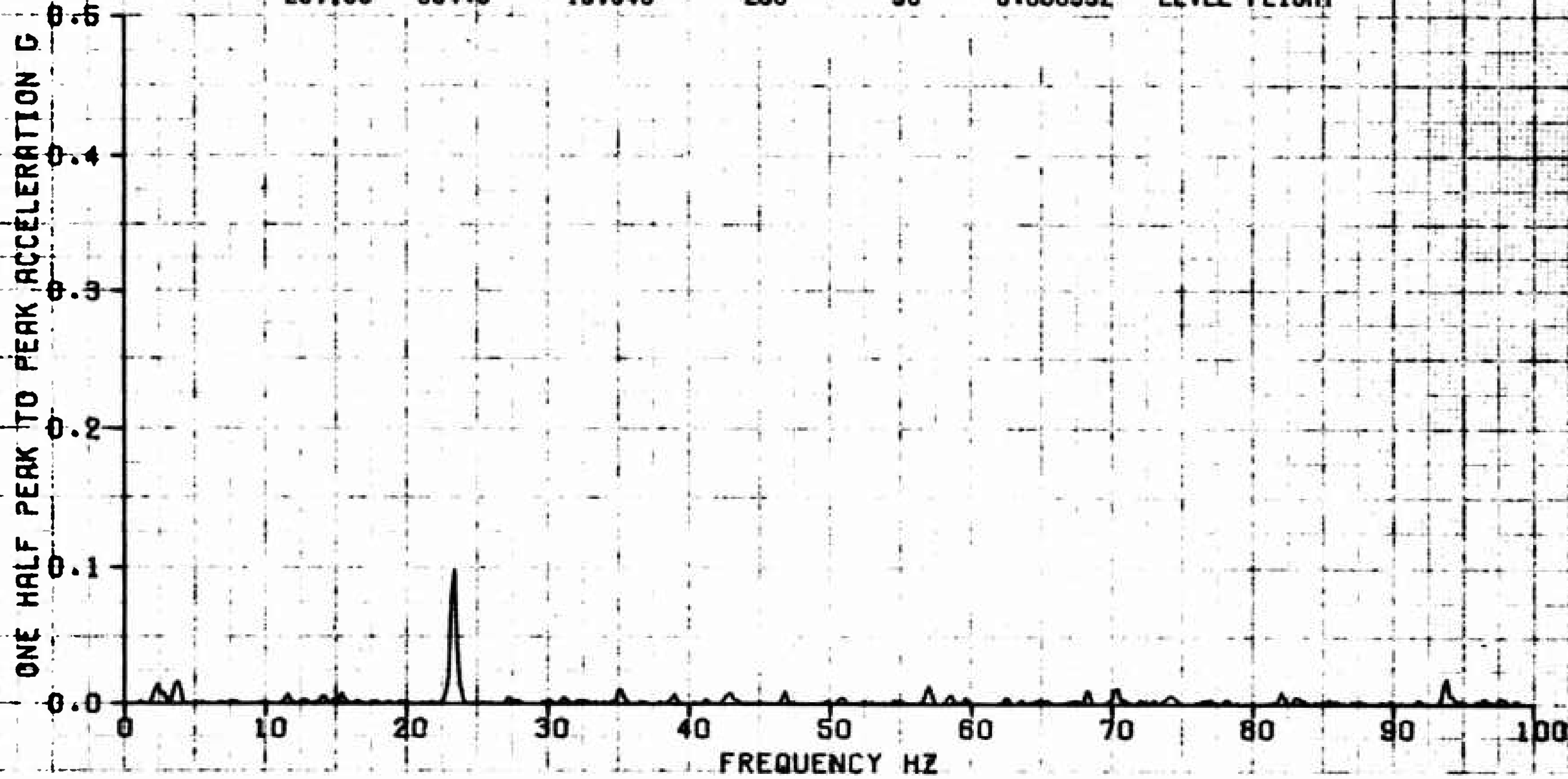


FIG 10

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS
CH-47C USA S/N 69-17126
FLIGHT 5

PILOT SEAT LATERAL
IN ICING CLOUD PRIOR TO FIRST ASYMMETRIC ICE SHED

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28,100	334.0	10,840	235	98	0.005332	LEVEL FLIGHT

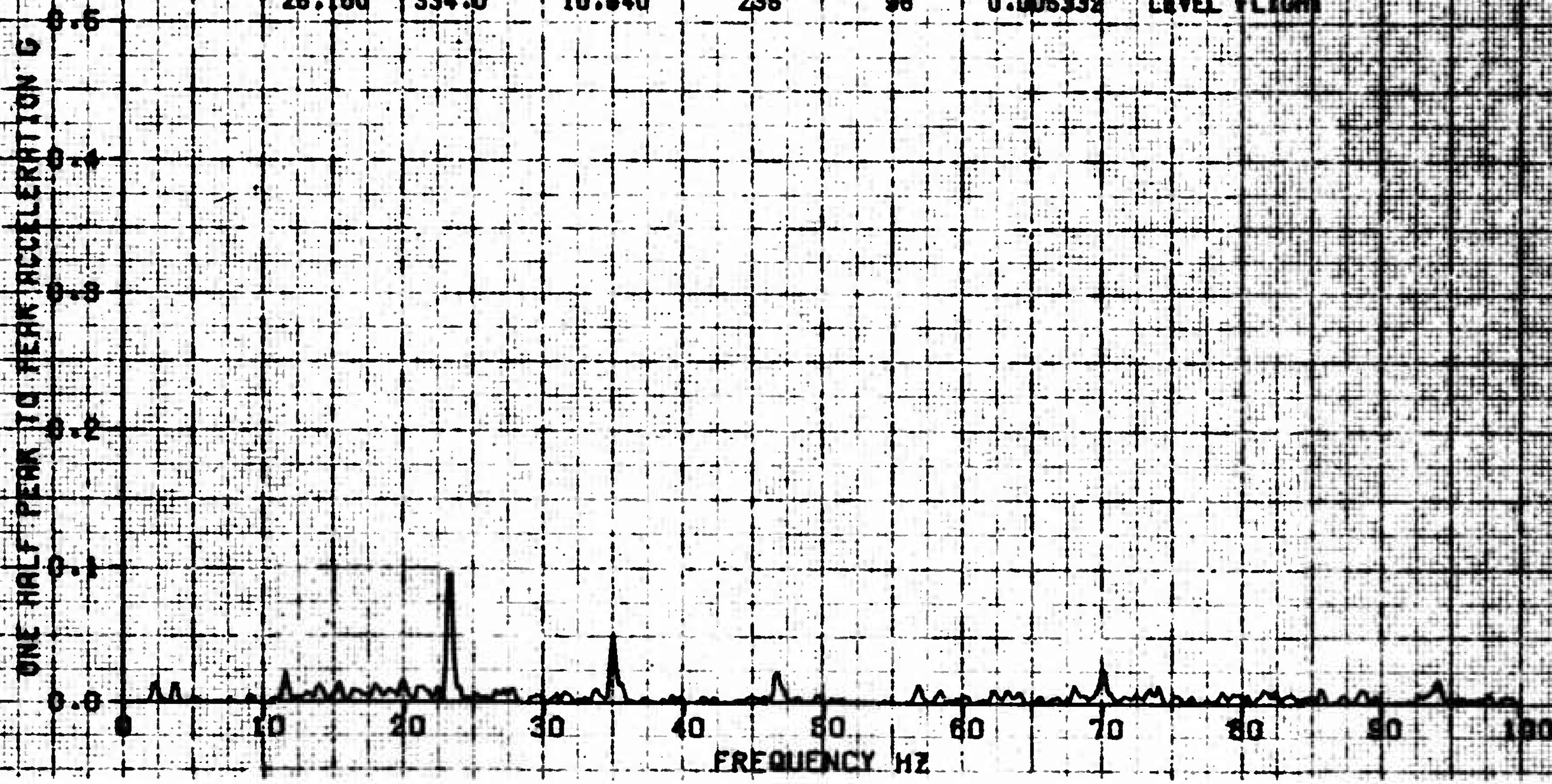


FIG 11

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 69-17126

FLIGHT 5

PILOT SEAT LATERAL

FIRST ASYMMETRIC ICE SHED

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28.100	334.0	10.840	235	98	0.005332	LEVEL FLIGHT

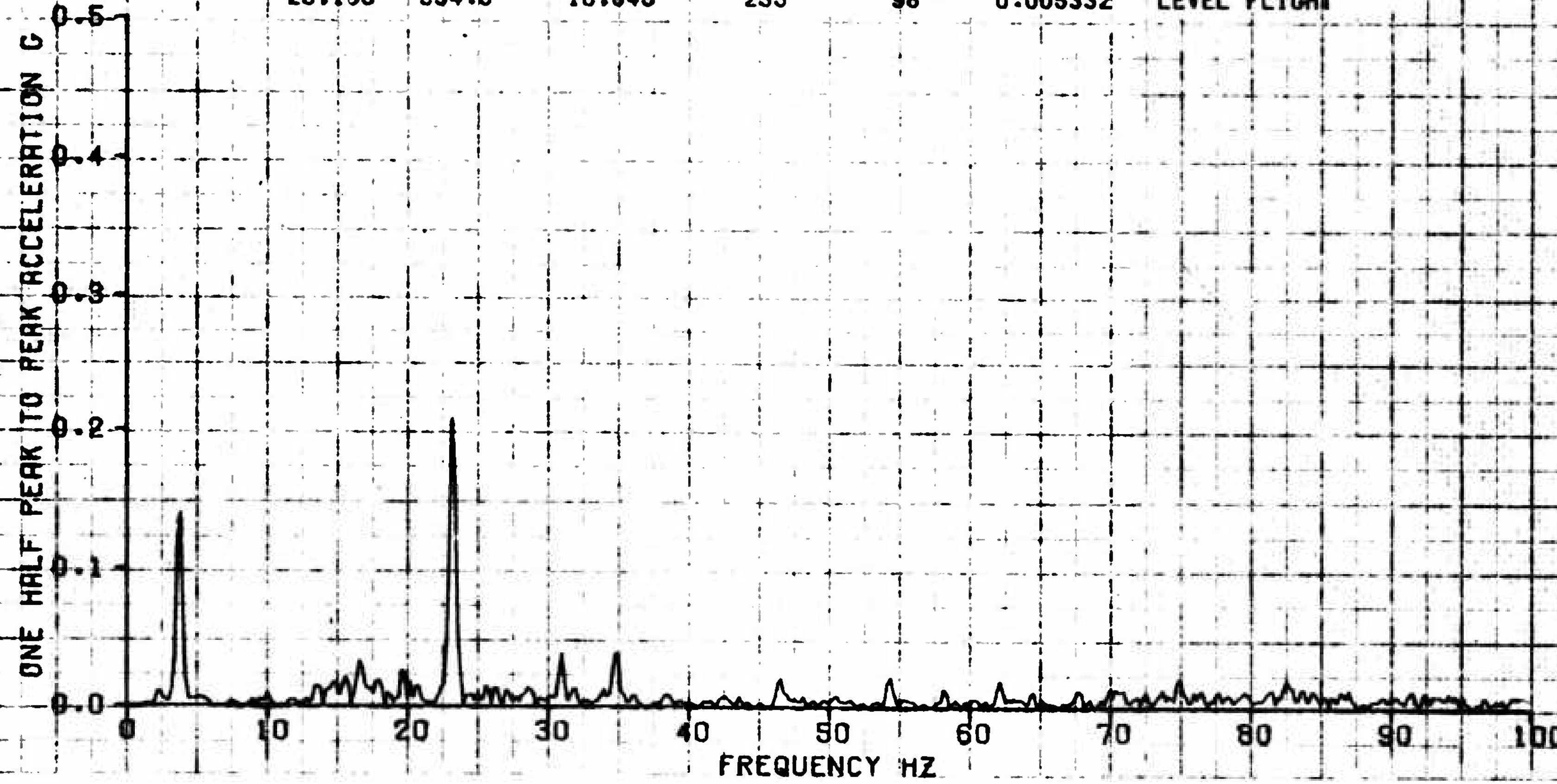


FIG 12

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 69-17126

FLIGHT 5

PILOT SEAT LATERAL

AFTER FIRST ASYMMETRIC ICE SHED RETURNED TO NORMAL

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28.100	334.0	10.840	235	98	0.005332	LEVEL FLIGHT

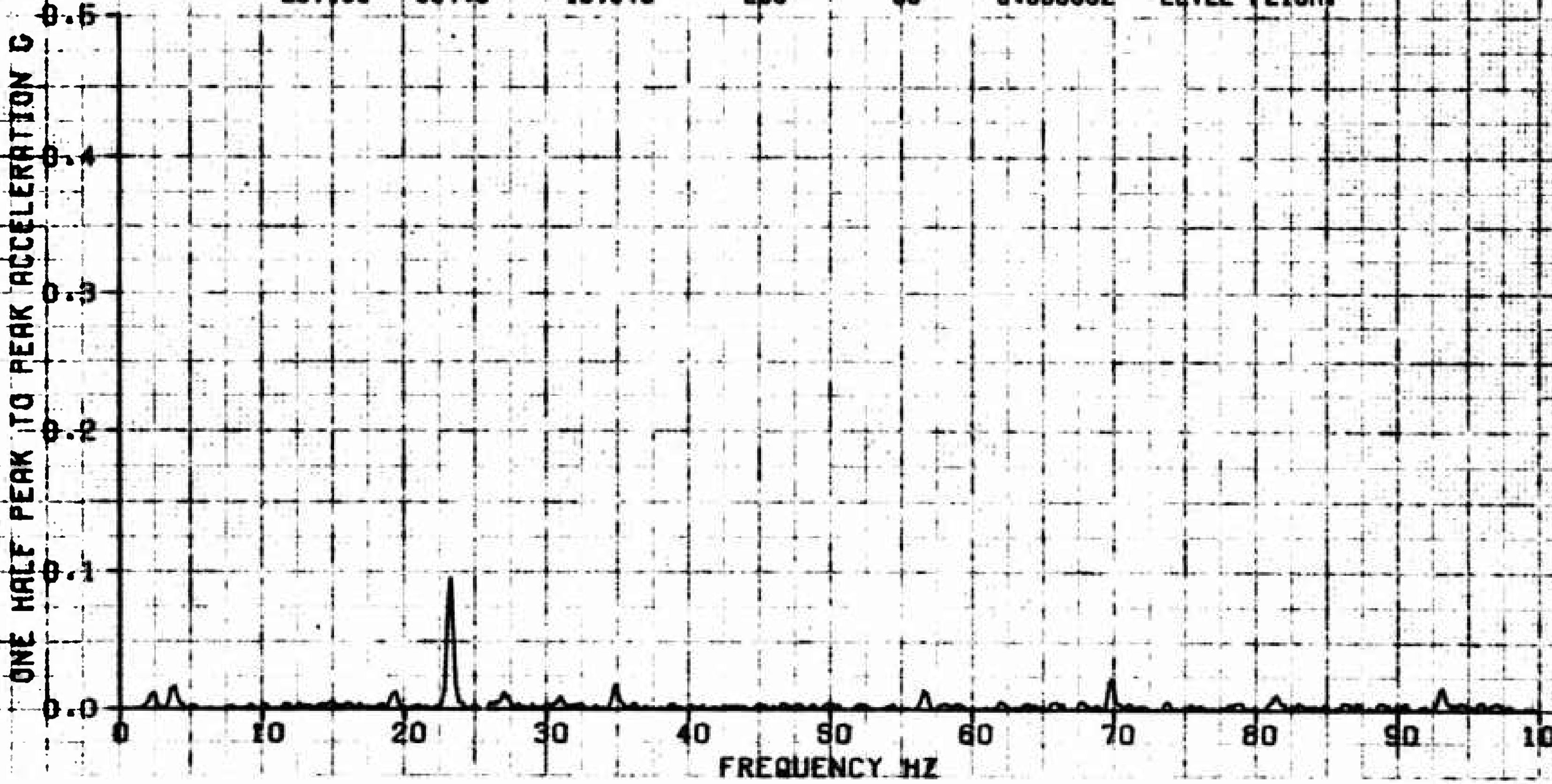


FIG 13
VIBRATION CHARACTERISTICS
ARTIFICIAL ICING TESTS
CH-47C USA S/N 69-17126
FLIGHT 5
PILOT SEAT LATERAL
IN ICING CLOUD PRIOR TO SECOND ASYMMETRIC ICE SHED

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28,100	334.0	10,840	235	98	0.006332	LEVEL FLIGHT

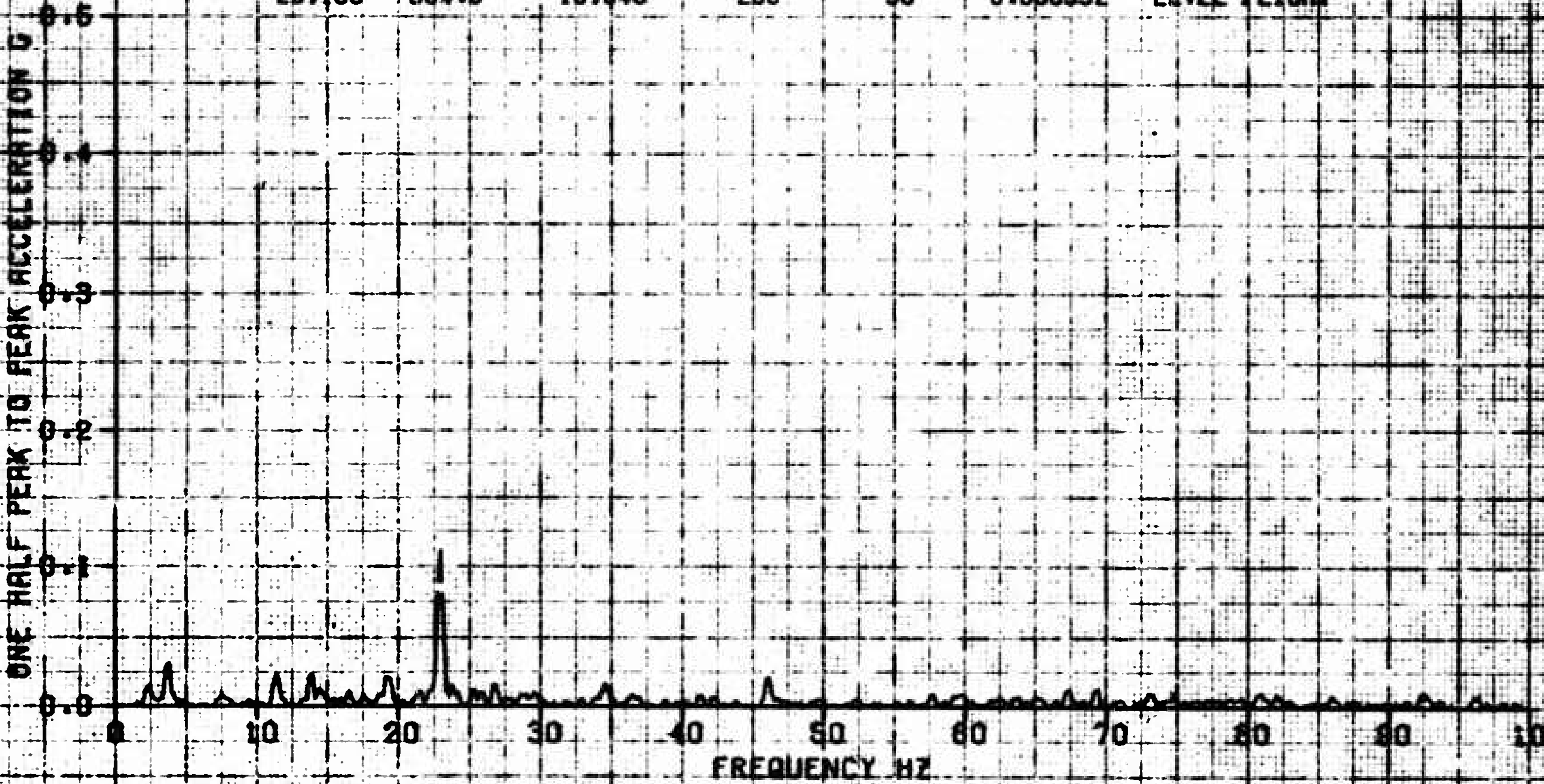


FIG 14

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 69-17126

FLIGHT 5

PILOT SEAT LATERAL

SECOND ASYMMETRIC ICE SHED

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28.100	334.0	10.640	236	98	0.005332	LEVEL FLIGHT

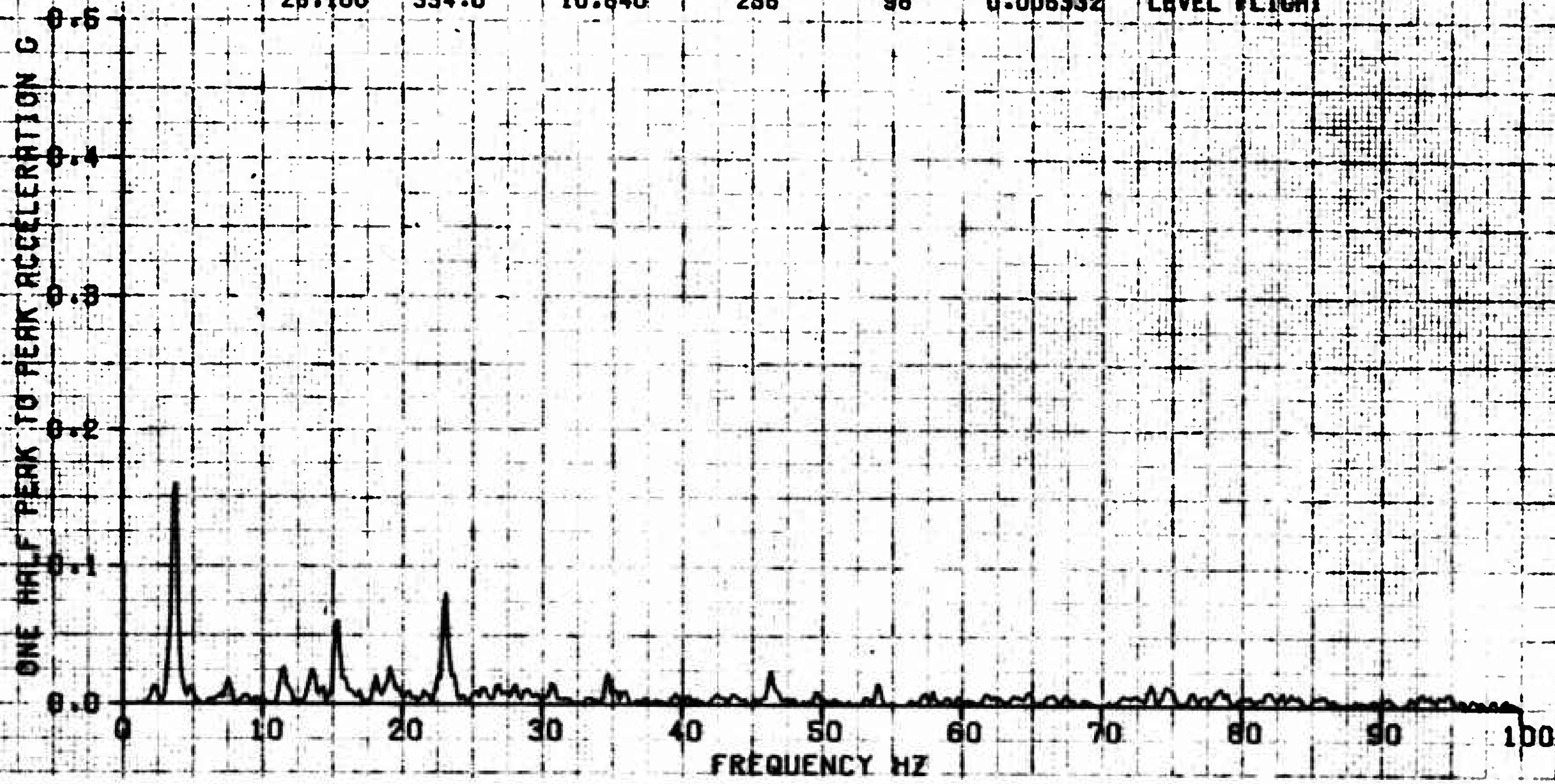


FIG 15
VIBRATION CHARACTERISTICS
ARTIFICIAL ICING TESTS
CH-47C USA S/N 69-17126
FLIGHT 5
PILOT SEAT LATERAL
AFTER SECOND ASYMMETRIC ICE SHED RETURNED TO NORMAL

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28.100	334.0	10.840	235	98	0.006332	LEVEL FLIGHT

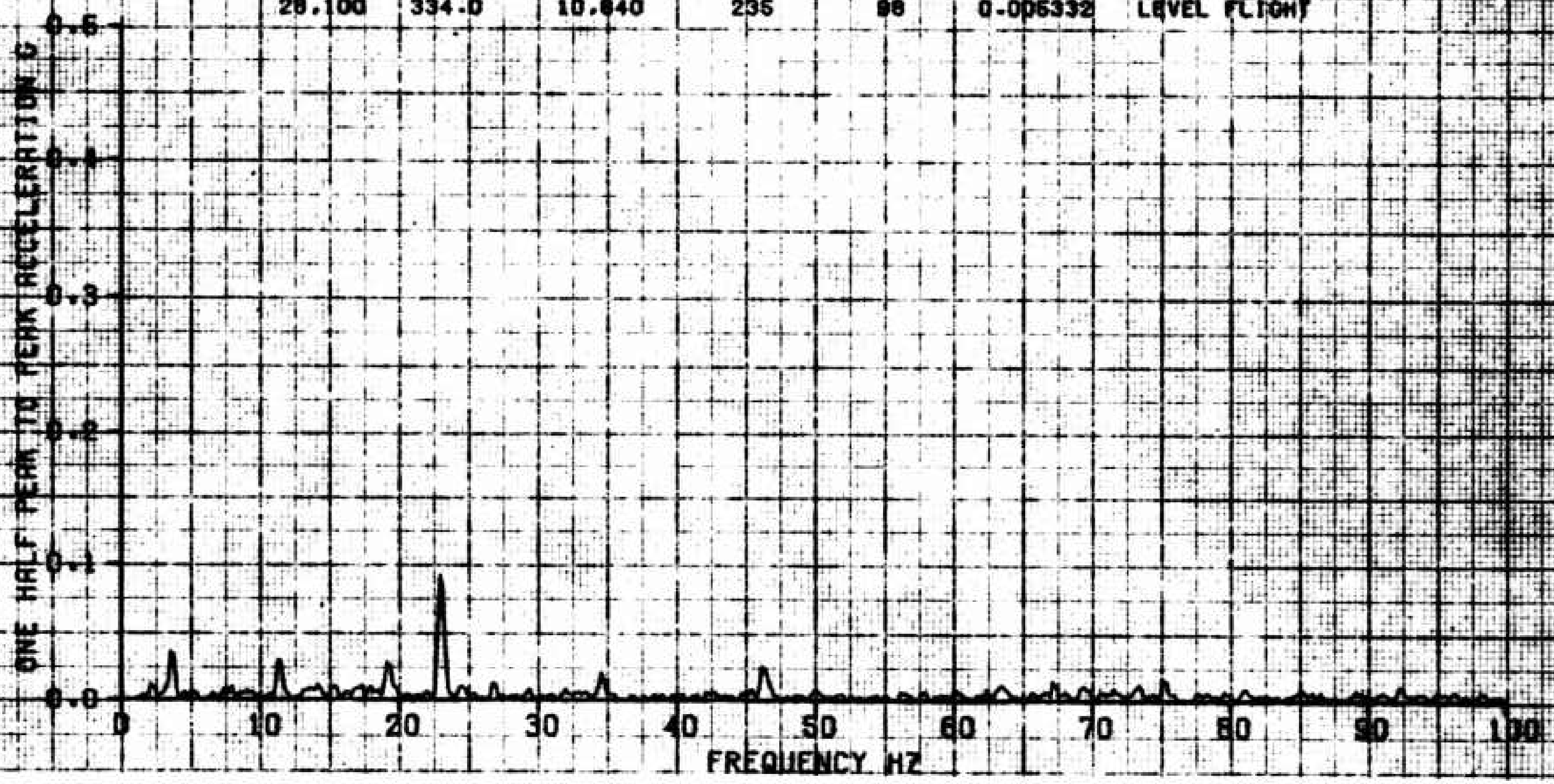


FIG 16

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 69-17126

FLIGHT 5

PILOT SEAT LONGITUDINAL

TRIM NO ICE

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28,100	334.0	10,840	235	98	0.005332	LEVEL FLIGHT

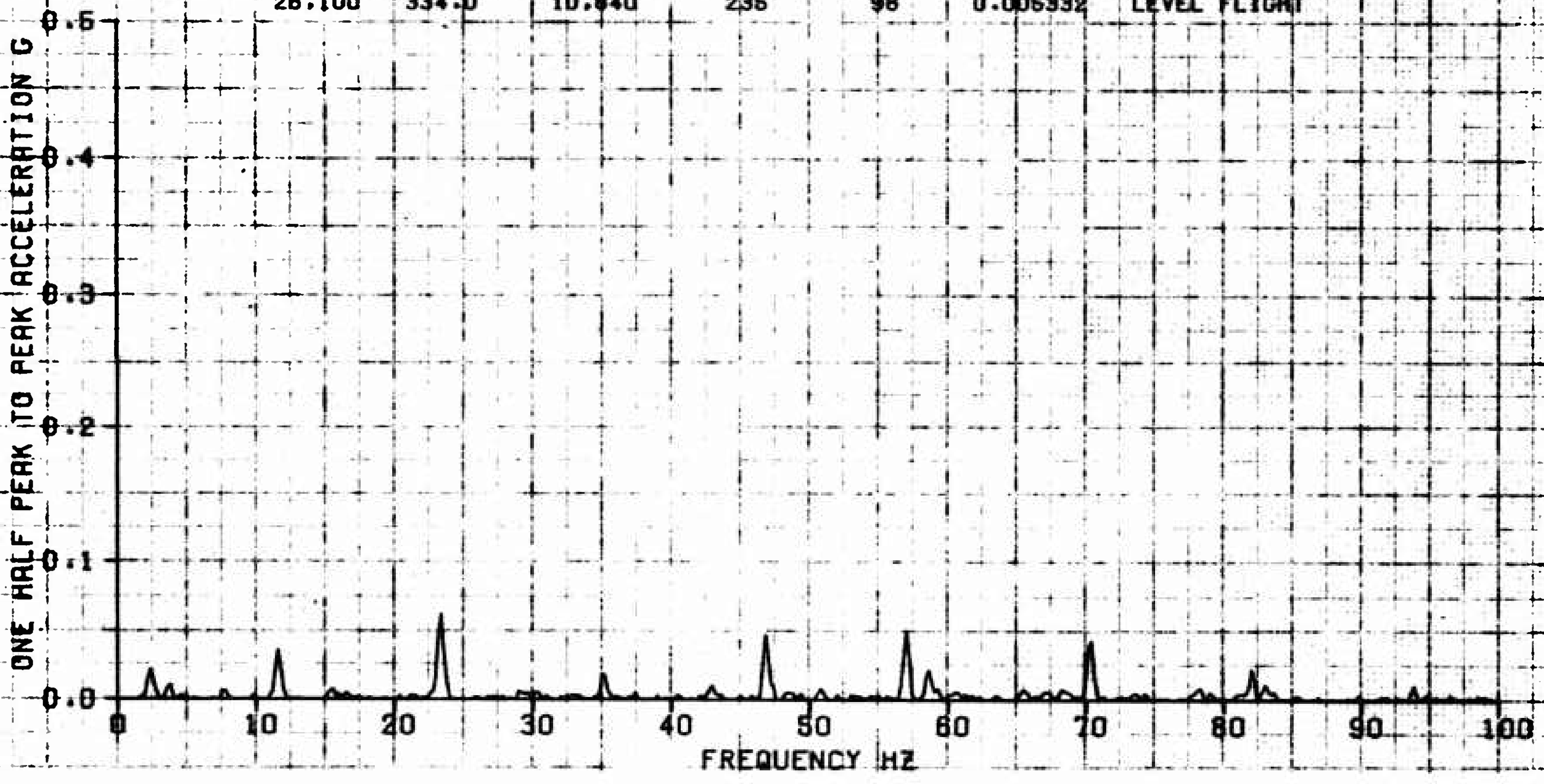


FIG 17

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 68-17125

FLIGHT 5

PILOT SEAT LONGITUDINAL

IN ICING CLOUD PRIOR TO FIRST ASYMMETRIC ICE SHED

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28.100	334.0	10.840	235	96	0.005332	LEVEL FLIGHT

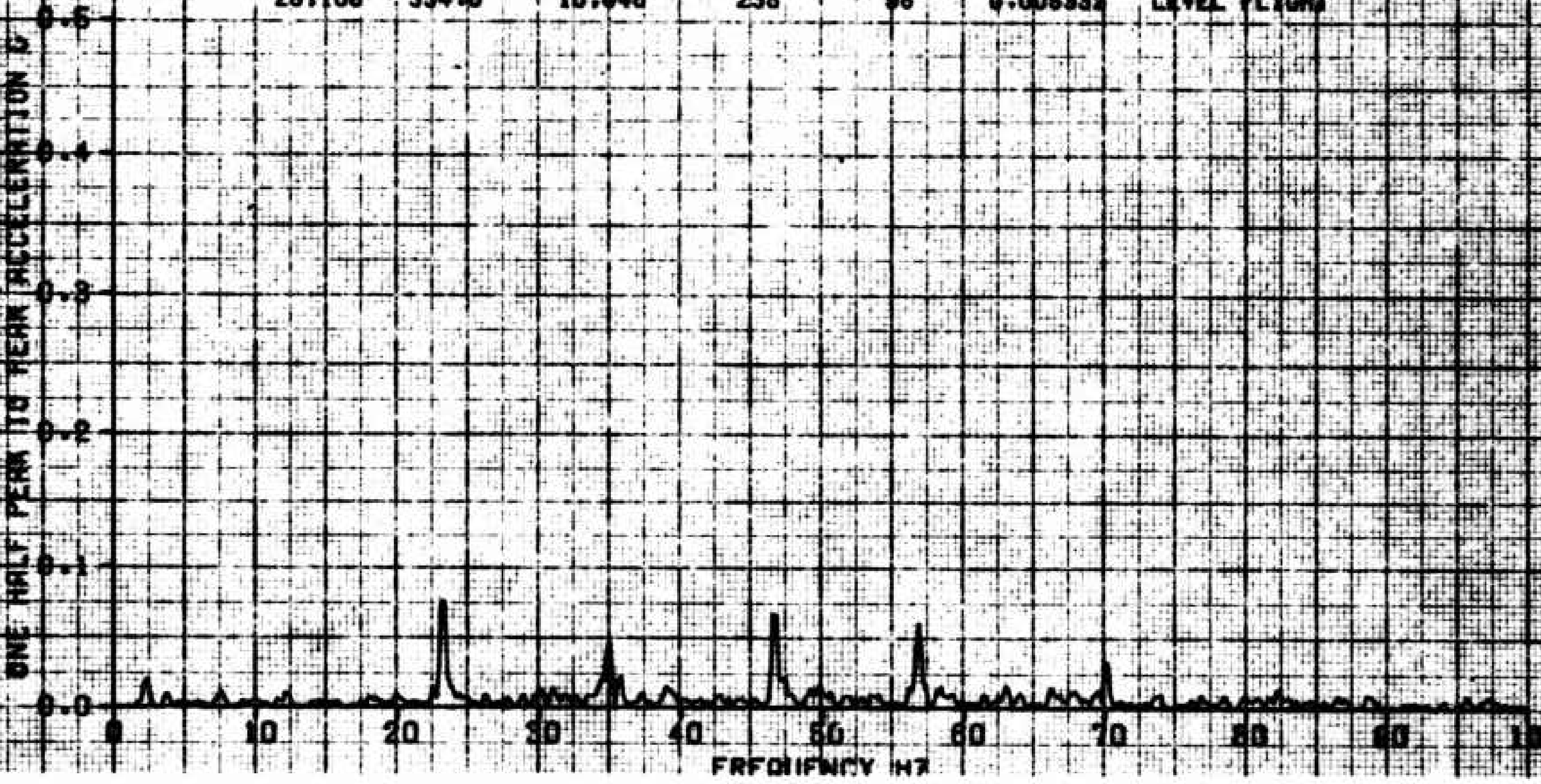


FIG 18
VIBRATION CHARACTERISTICS
ARTIFICIAL ICING TESTS
CH-47C USA S/N 69-17126
FLIGHT 5
PILOT SEAT LONGITUDINAL
FIRST ASYMMETRIC ICE SHED

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28,100	334.0	10,840	236	98	0.006332	LEVEL FLIGHT

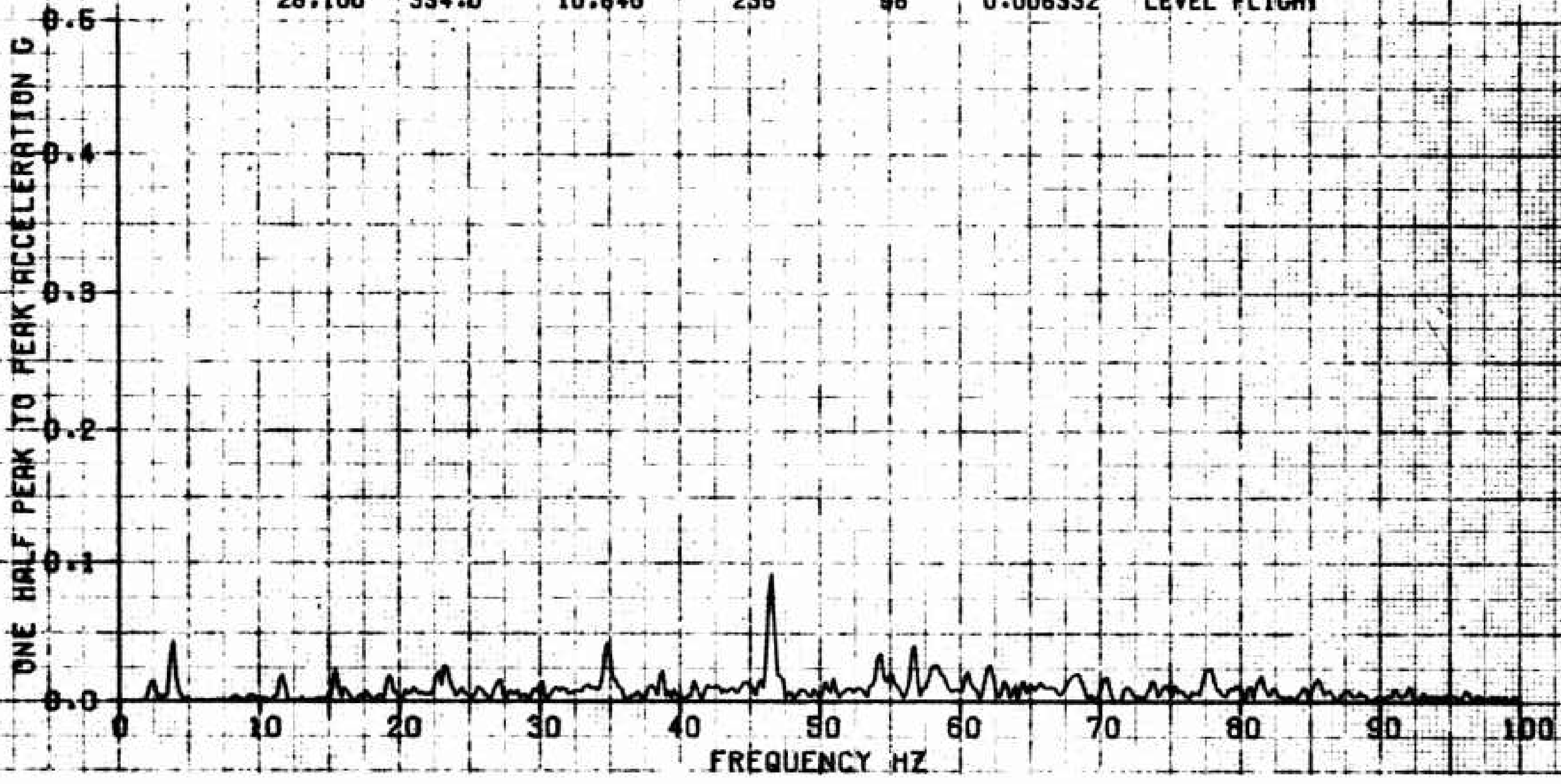


FIG 19

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS
CH-47C USA S/N 69-17126
FLIGHT 5
PILOT SEAT LONGITUDINAL
AFTER FIRST ASYMMETRIC ICE SHED RETURNED TO NORMAL

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28,100	334.0	10,840	235	98	0.006332	LEVEL FLIGHT

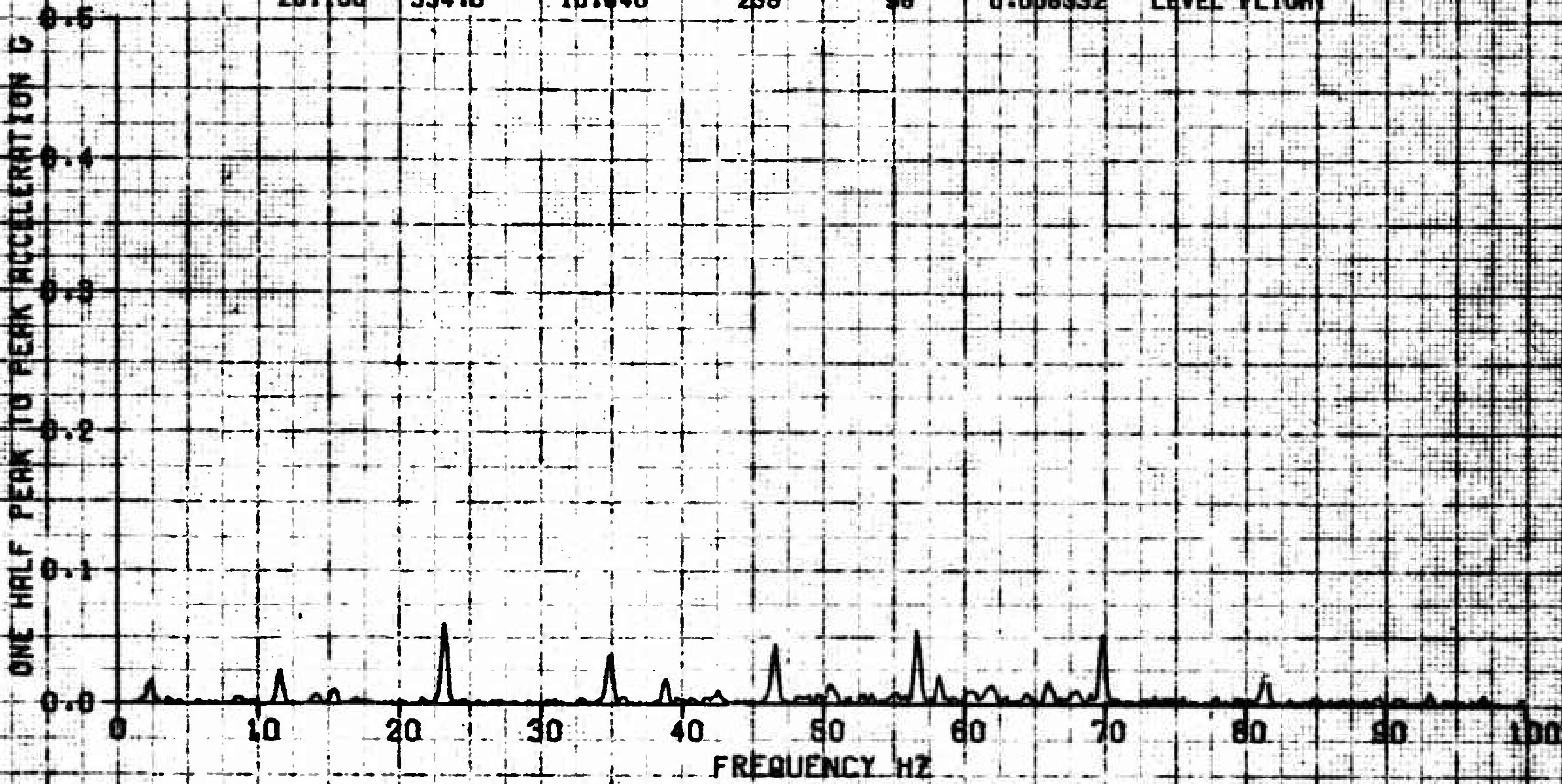


FIG 20

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 69-17126

FLIGHT 5

PILOT SEAT LONGITUDINAL

IN ICING CLOUD PRIOR TO SECOND ASYMMETRIC ICE SHED

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28.100	334.0	10.840	236	98	0.006332	LEVEL FLIGHT

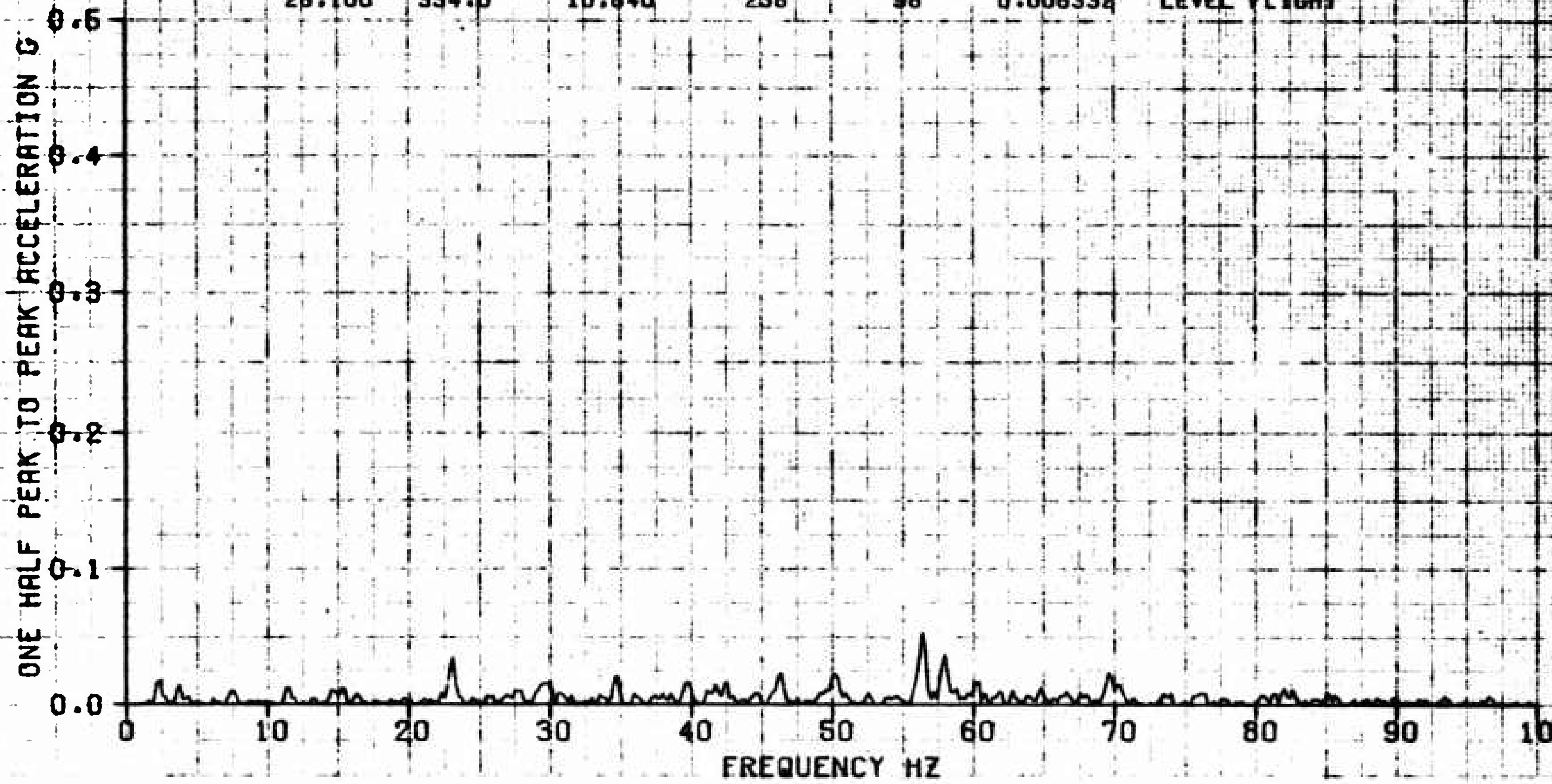


FIG 21

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 69-17126

FLIGHT 5

PILOT SEAT LONGITUDINAL

SECOND ASYMMETRIC ICE SHED

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28,100	334.0	10,840	235	98	0.005332	LEVEL FLIGHT

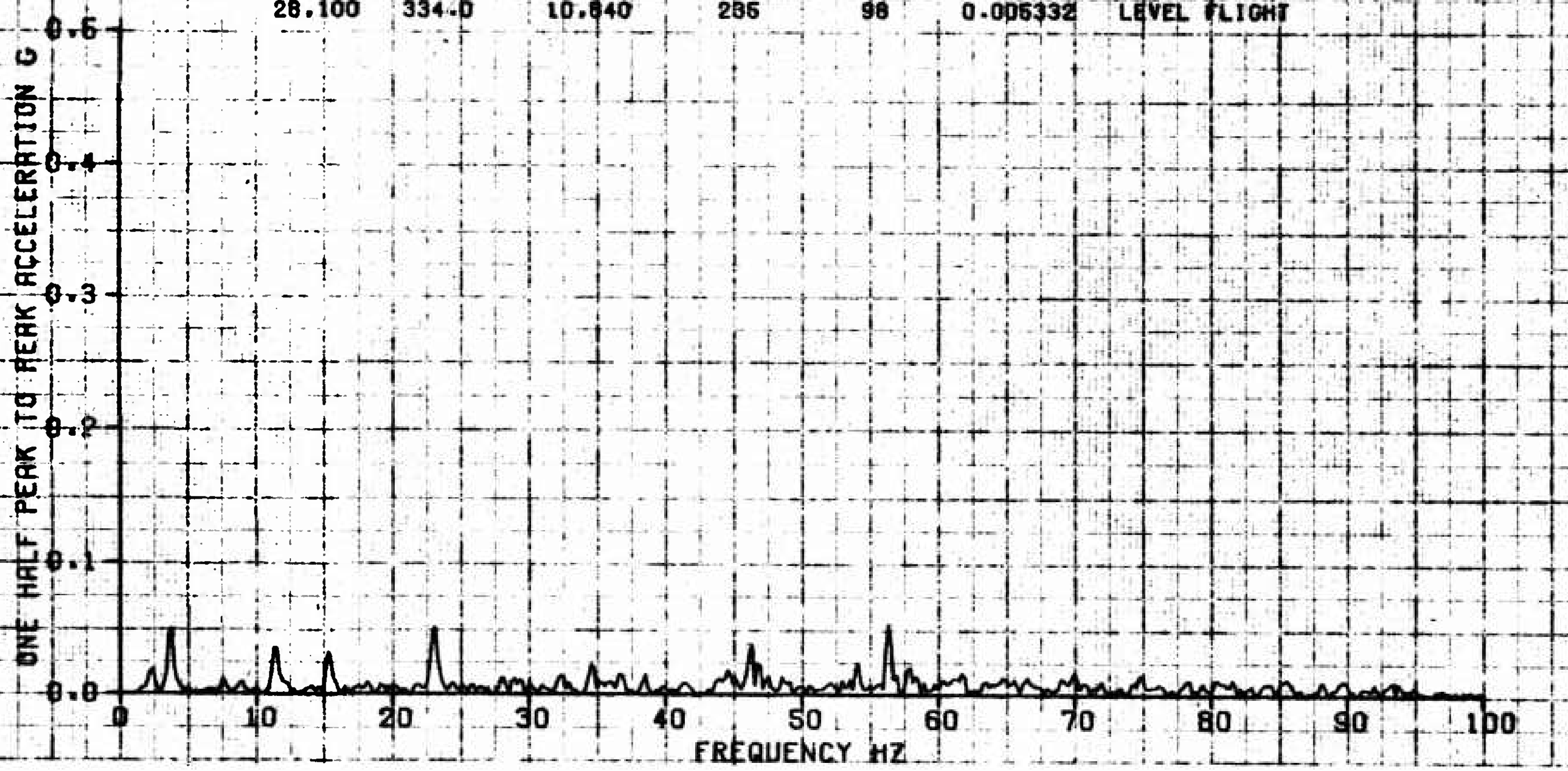


FIG 22

VIBRATION CHARACTERISTICS

ARTIFICIAL ICING TESTS

CH-47C USA S/N 69-17126

FLIGHT 5

PILOT SEAT LONGITUDINAL

AFTER SECOND ASYMMETRIC ICE SHED RETURNED TO NORMAL

AVG GROSS WEIGHT (LBS)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG ROTOR SPEED (RPM)	AVG TRUE AIRSPEED (KTAS)	AVG COEFFICIENT OF THRUST	FLIGHT CONDITION
28,100	334.0	10,840	236	98	0.006332	LEVEL FLIGHT